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JADS JT&E

End-to-End Test Interim Report Phase 1

By: Lt Col James M. McCall and Gary Marchand

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Joint Advanced Distributed Simulation
Joint Test Force
2050A 2nd St. SE
Kirtland Air Force Base, New Mexico 87117-5522

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1.0 Introduction

1.1 Joint Advanced Distributed Simulation Overview

The Joint Advanced Distributed Simulation Joint Test and Evaluation (JADS JT&E) was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation), Office of the Under Secretary of Defense (Acquisition and Technology) in October 1994 to investigate the utility of advanced distributed simulation (ADS) technologies for support of developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). The program is Air Force led, with Army and Navy participation. The Joint Test Force (JTF) manning includes 23 Air Force, 13 Army, and 2 Navy. Science Applications International Corporation and Georgia Tech Research Institute provide contracted technical support. The program is nominally scheduled for five years.

The JADS JT&E charter focuses the evaluation of utility on three issues: (1) What is the present utility of ADS, including distributed interactive simulation (DIS), for T&E? (2) What are the critical constraints, concerns, and methodologies when using ADS for T&E? (3) What are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future. From these issues, objectives and measures have been developed to guide the evaluation.

The JADS JT&E is directly investigating ADS applications in three slices of the T&E spectrum: a System Integration Test (SIT) which explores ADS support of air-to-air missile testing, an End-To-End (ETE) Test which explores ADS support for command, control, communications, computers, and intelligence, surveillance and reconnaissance (C4ISR) testing, and an Electronic Warfare (EW) Test which explores ADS support for EW testing. Each test will apply the JADS objectives and measures as appropriate to conduct their evaluation. The JTF is also chartered to observe, or participate at a modest level, in ADS activities sponsored and conducted by other agencies in an effort to broaden conclusions developed in the three dedicated test areas.

The JADS ETE Test is the subject of this report and is described in the next section; the following is a brief synopsis of the SIT and EW tests.

The SIT evaluated the utility of using ADS to support cost-effective testing of an integrated missile weapon/launch aircraft system in an operationally realistic scenario. The SIT also evaluated the capability of the JADS Test Control and Analysis Center (TCAC) to control a distributed test of this type and to remotely monitor and analyze test results. The SIT consisted of two phases, each of which culminated in three flight missions. The missions simulated a single shooter aircraft launching an air-to-air missile against a single target aircraft. In the Linked Simulators Phase (LSP), the shooter, target, and missile were all represented by simulators. In the Live Fly Phase (LFP), the shooter and target were represented by live aircraft and the missile by a simulator.

The EW test will evaluate the utility of ADS in a distributed EW test environment. The first phase is open air testing to develop a performance baseline for two subsequent test phases. The first distributed

test phase employs a linked architecture utilizing Department of Defense's (DoD) high level architecture (HLA) which includes a digital simulation model of the ALQ-131 self-protection jammer, threat simulation facilities, and constructive models which support replication of the open air environment. In the second phase, an installed systems test facility is substituted for the digital model. In both distributed test architectures, system performance data will be compared with live fly data for verification and validation (V&V).

1.2 Test Overview

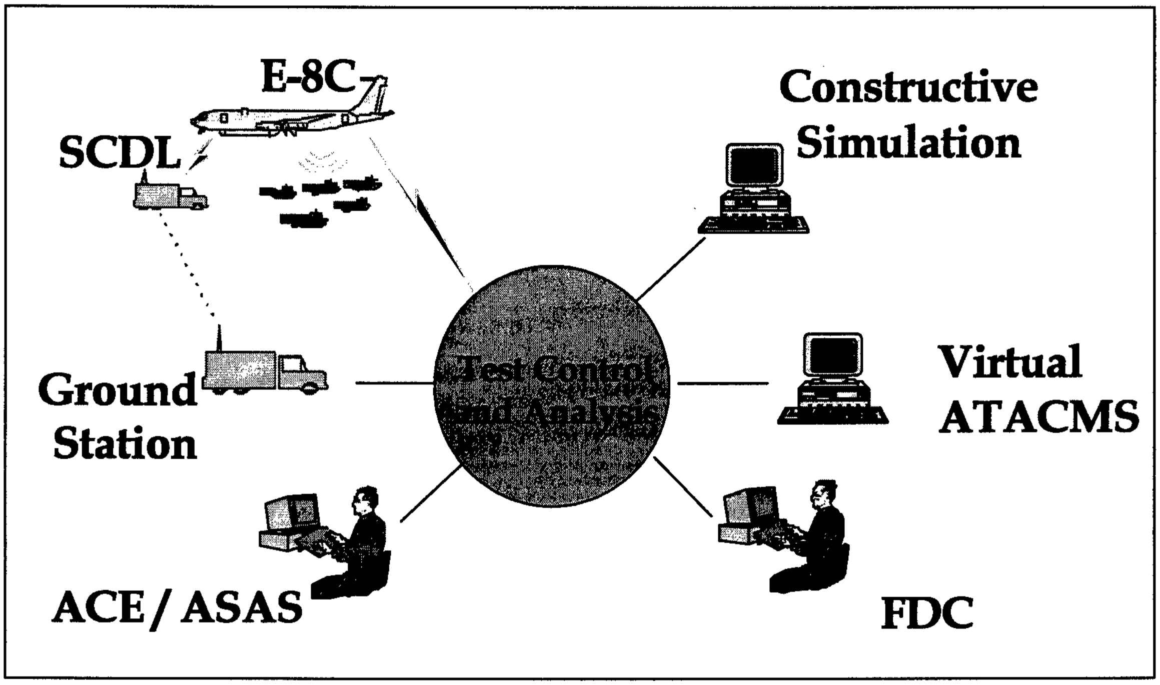
The ETE test is designed to evaluate the utility of ADS to support testing of C4ISR systems. The test will use the developmental and operational testing issues for the Joint Surveillance Target Attack Radar System (Joint STARS) to conduct its T&E utility evaluation in an ADS-enhanced test environment. Additionally, ETE also includes an evaluation of JADS Test Control and Analysis Center's (TCAC) capability to control a distributed test of this type and remotely monitor and analyze test results

The ETE is using distributed simulation to assemble an enhanced environment to be used for testing C4ISR systems. The intent is to provide a complete, robust set of interfaces from sensor to weapon system including the additional intermediate nodes that would be found in a tactical engagement. The test will trace a thread of the complete battlefield process from target detection to target assignment and engagement at corps level using ADS. It will allow the tester to evaluate the thread as a whole or the contribution of any of the parts individually and to evaluate what effects an operationally realistic environment has on the system under test.

The major focus of the ETE is the evaluation of ADS enhancements to the testing of Joint STARS. A limitation identified in the Joint STARS multi-service operational test and evaluation (MOT&E) plan was the inability to test Joint STARS ability to support a notional corps area of interest. As a result of this limitation, many of the MOT&E measures were or will be collected under conditions short of the projected Joint STARS operational environment.

Thus, the ETE is designed to add additional entities in a seamless manner to the battlefield seen by the Joint STARS. In addition, adding some of the complementary suite of other C4I and weapon systems with which Joint STARS would interact will enable the test team to evaluate the utility of an ADS-enhanced test environment.

The test concept (Figure 1) is to use ADS to supplement the operational environment the E-8C and ground station module (GSM) operators would experience. By mixing the available live targets with targets generated by a constructive model, a battle array that approximates the major systems present in a notional corps area of interest can be presented. Additionally, by constructing a network with nodes representing appropriate C4I and weapon systems, a more robust cross section of players is available with which the E-8C and GSM operators can interact.



ACE - analysis and control element
ASAS - All Source Analysis System
ATACMS - Army Tactical Missile System
FDC - fire direction center
SCDL - surveillance control data link

Figure 1. ETE Test Concept

Several components are required to create the ADS-enhanced operational environment that will be used in the ETE. In addition to Joint STARS, the ETE will require a validated simulation capable of generating entities that will represent the elements in the rear of a threat force. Also, simulations of the Joint STARS moving target indicator (MTI) radar and synthetic aperture radar (SAR) will be used to insert the simulated entities into the radar stream aboard the E-8C while it is flying a live mission. Other capabilities used to support the test include a subset of the Army's analysis and control element (ACE), simulations or subsets of the Army's artillery command and control process, and a simulation of the Army's Advanced Tactical Missile System (ATACMS). Communications among these simulations will be accomplished using doctrinally correct Advanced Field Artillery Tactical Data System (AFATDS) message traffic and DIS protocol data units (PDU).

The ETE test consists of four phases. Phase 1 develops or modifies the components that allow the mix of live and simulated targets at an E-8C operator's console and ground station module (GSM) operator's console. Phase 2 evaluates the utility of ADS to support DT&E and early OT&E of a C4ISR system in a laboratory environment. Phase 3 transitions portions of the architecture to the E-8C and ensures the components function properly and the synthetic environment interacts with the aircraft and the actual GSM in a proper manner. Phase 4 evaluates the ability to perform test and evaluation of the E-8C and GSM in a synthetically enhanced operational environment using typical operators.

2.0 Phase 1 Overview

2.1 Phase 1 Purpose

The purpose of Phase 1 is to develop, modify, and integrate software and hardware which will be used to establish the ETE test environment as well as plan and coordinate activities for Phases 2 through 4.

The ETE environment components developed during Phase 1 consist of a constructive simulation to provide virtual targets, an E-8C simulation called the Virtual Surveillance Target Attack Radar System (VSTARS), an interface to allow surveillance and control data link (SCDL) traffic from VSTARS to be displayed in the GSM, and an ADS network suitable for integration and testing.

2.2 Phase 1 Approach

The JADS ETE team developed requirements for a constructive simulation and then evaluated available constructive simulations against these requirements. The Janus simulation developed and managed by the U.S. Army Training and Doctrine Command (TRADOC) Analysis Center, White Sands Missile Range (TRAC-WSMR), New Mexico, was selected as the simulation which had the best potential of being modified to meet JADS requirements. TRAC-WSMR expanded the Janus scenario driver into Janus 6.88D, a constructive simulation capable of supporting up to 10,000 individual entities with a distributed interactive simulation (DIS) interface to the ETE environment.

The JADS ETE team investigated existing simulations of Joint STARS and determined that none of the existing simulations met the fidelity requirements. Northrop Grumman, the developer of the E-8C, performed the engineering and development of both a laboratory emulation of the E-8C radar subsystem and the capability to integrate the E-8C into a synthetic environment. The VSTARS is a laboratory emulation of the E-8C radar subsystem and other aircraft components which can receive synthetic targets from a DIS network and provide the stimulus to display these targets on the Advanced Technology Work Station (ATWS) or on the ground station module. The radar processor simulator and integrator (RPSI) and the air network interface unit (ANIU) are the portions of the VSTARS which are installed on the aircraft.

One of the more challenging aspects of Phase 1 was developing a near real-time simulation of the E-8C synthetic aperture radar (SAR). JADS ETE, through the Advanced Research Projects Agency (ARPA) War Breaker project, conducted a trade study of various existing simulations. We selected the XPATCHES simulation developed by Wright Laboratory (Dayton, Ohio) and Loral Defense Systems (Goodyear, Arizona) as being the best starting point for the E-8C SAR simulation. Lockheed Martin Tactical Data Systems, Goodyear, Arizona, developed a SAR simulation that emulates the Joint STARS SAR operation. This simulation system is referred to as the Advanced Radar Imaging Emulation System (ARIES) and is operationally embedded into Northrop Grumman's radar processor simulation and integrator RPSI.

The normal connection between the E-8C and its associated ground stations is through a line-of-sight data link called the surveillance control data link (SCDL). After considerable investigation, the JADS ETE team determined this link could not be easily transmitted via commercial communications lines. Based on discussions among the team, Northrop Grumman, and Motorola, we determined the best approach would be to develop interfaces which transferred the normal message traffic between the E-8C and GSM rather than attempting to transfer the SCDL messages directly. Northrop Grumman and Motorola developed an interface control document which defined this message traffic. Northrop Grumman included the capability in VSTARS to capture these messages and divert them to an Ethernet, and Motorola developed an interface unit between the GSM and an Ethernet. This interface unit links the Ethernet with the internal 1553 databus of the GSM. Additionally, the interface unit simulates the operation of the ground data terminal forcing the GSM operator to perform the normal linking process prior to receiving the message traffic from VSTARS.

Initially, network equipment installed in Phase 1 connected TRAC-WSMR with the JADS TCAC at Albuquerque, New Mexico, and then extended the network from the TCAC to the Northrop Grumman laboratory facilities at Melbourne, Florida. Late in Phase 1, this network was extended to include links from the TCAC to Fort Hood, Texas, and Fort Sill, Oklahoma, and a link between Northrop Grumman and Fort Hood.

During Phase 1, the JADS team evaluated two logger capabilities for use during the ETE test. One of these was developed in support of Janus and the other is a product from the U.S. Army Simulation, Training, and Instrumentation Command. The primary concern was to evaluate or establish the ability to accurately log large numbers of protocol data units (PDUs) over several hours. Several shortcomings of both of these products led the JADS team to develop the JADS logger. The JADS team also developed a set of data reduction and analysis tools in support of the ETE test.

2.3 Phase 1 Schedule

The schedule for Phase 1 was driven by the availability of funding and by contracting delays. Due to funding constraints during fiscal year (FY) 95, the ETE test was limited to modification of Janus and to conducting architecture and engineering studies on the Joint STARS simulation. Initial contracting for the studies required eight months and actual development of the RPSI and ARIES did not begin until FY97. Figure 2 is the as built schedule for Phase 1.

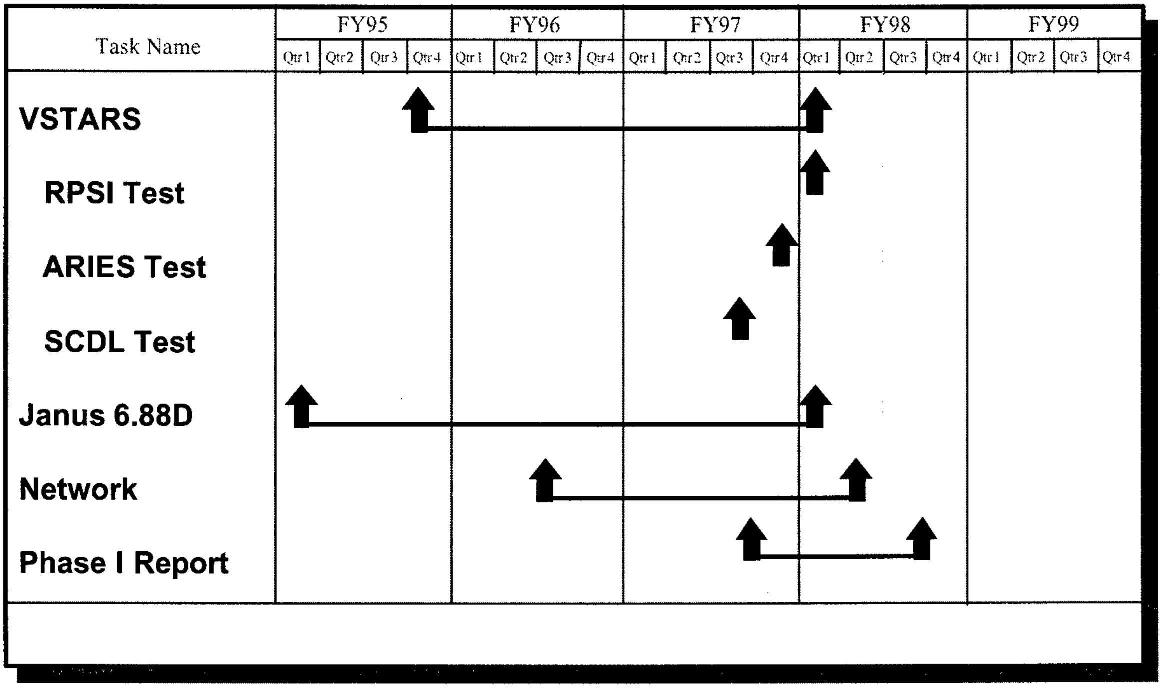


Figure 2. Phase 1 Schedule

2.4 Phase 1 Costs

Table 1 outlines the costs for Phase 1.

Table 1. Phase 1 Costs

Element of Cost	Cost	Total
Janus 6.88D	$462,000	$462,000
Janus Hardware Suite (2)		$80,000
E-8C Simulation		$2,617,560
Architecture/Engineering Design	$678,000	
Development/Integration	$1,839,560	
Contracting Fee	$100,000	
ARIES Development		$864,450
Development	$832,830	
Contracting Fee	$31,620	
SCDL Link Development		$327,490
Network Leases		$90,312
Network Equipment and Instrumentation		$173,720
Test Team Expenses		$114,360
Hardware/Software	$21,040	
Travel	$85,530	
Training	$7,790	

Total Phase 1 Costs $4,729,892

3.0 Phase 1 Results

3.1 Constraints, Concerns, and Methodologies When Using ADS

One of the key constraints identified for JADS is the ability of the DoD infrastructure to support ADS test and evaluation. A measure of this constraint is found in the amount of development required to establish a synthetic environment with which to conduct testing. The ETE test provides insight into the amount of development required to support a test of this type and demonstrates the application of a systems engineering methodology to identify the requirements for ADS components, evaluate the availability of ADS components, and modify or develop the components to meet the requirements.

3.1.1 Constructive Simulation - Janus 6.88D

To generate the notional corps rear area, a constructive, entity-level simulation was required. The following represents the requirements developed to evaluate the capability of various existing simulations to support the JADS ETE.

Requirements:

- Capable of simulating, or of being modified to simulate, at least 5000 distinct entities with at least twenty-five percent moving in a reasonable and affordable manner.
- Capable of issuing DIS 2.0.4 entity state (ES) PDUs that describe each entity simulated.
- Capable of receiving and acting upon ESPDUs, fire PDUs, and detonation PDUs.
- Capable of running for at least eight hours with human intervention as required.
- Capable of running at or representing real-time actions.
- Must use terrain data base at least 200 kilometers (km) by 200 km and based on National Imagery and Mapping Agency products.
- Must have a V&V history, an accreditation history for analysis, be under configuration control, and be well documented.
- Must reasonably represent entity movement, stopping, and turning.
- Must represent the effects of a bombing or missile attack on the entities represented in an acceptable and credible manner.

This analysis indicated that none of the constructive simulations would meet the ETE requirements without modification and development. JADS ETE identified the following criteria from the requirements for selecting which simulation to modify.

1. Capable of producting large numbers (1000s) of "intelligent" (semiautomated, nonscripted, nontemplated, human controllable) interactive entities.
2. Capable of conducting the simulation in a large terrain box (preferably at least 200 km by 200 km) while operating at the entity level described in 1.

3. Previously verified and validated (preferably by the Army) for combat development and OT/DT studies.
4. DIS compatible.

Table 2 provides the comparison of the constructive simulations which led to the selection of the Janus simulation as the best candidate for upgrading to meet our requirements.

Table 2. Constructive Simulation Comparison

CRITERIA	EAGLE	CBS	BBS	JCM	STAGE	JANUS	MODSAF
1	No	No	No	No	No	Yes	No
2	Yes	Yes	Yes	Yes	Yes	Yes	No
3	No	No	No	No	No	Yes	No
4	Yes	No	Yes	No	No	Yes	Yes

Janus is under the configuration control of the U.S. Army Training and Doctrine Command (TRADOC) Analysis Command, White Sands Missile Range (TRAC-WSMR) and the Army Simulation, Training, and Instrumentation Command (STRICOM). JADS entered into an agreement with TRAC-WSMR to modify Janus, as appropriate, to be able to represent at least 5000 entities. The entity-level data generated by Janus will be converted into ESPDUs by an interface developed by TRAC-WSMR for that purpose.

Janus is an interactive, computer-based simulation of combat operations conducted by platoons through brigades. The original Janus simulation began in the late 1970s at Lawrence Livermore National Laboratories to provide commanders interactive control of a combat simulation in the presence of nuclear effects. In 1983, TRAC-WSMR obtained Janus and enhanced Janus as a high-resolution simulation to support analysis for Army combat development. In 1991, TRADOC selected Janus for training at the company and platoon levels. Janus has also been used by the Command and General Staff College to train new battalion and brigade commanders on the principles of synchronized combined arms operations.

Janus is a suite of programs with over 200,000 lines of FORTRAN code. These programs produce an environment that allows the user to set up the desired battle. Terrain, performance data, forces, unit symbols, and command and control overlays are typical entities that can be edited to suit the user. Interactive graphics programs such as the Janus analyst workstation (JAAWS) and the controller workstation add to the utility of the Janus user's application tools.

TRAC-WSMR has an ongoing program of enhancement and improvement of Janus. JADS entered into an agreement with TRAC-WSMR and, with other programs, has sponsored various enhancements to Janus to allow it to meet ETE requirements. The result of these efforts is Janus 6.88D. Janus 6.88D provides capabilities which include enhancements sponsored by JADS or other programs in the following areas.

The number of units allowed in Janus was extended from 1200 to 6000, then to 8000, and most recently to 9999 in Janus 6.88D. Initial tests of even the first extension to 6000 units revealed that versions would not run real time. Further testing revealed the cause to be the updating of the unit locations on the graphic display. Major changes were required, and the solutions were creative, based on solid computer science theory, and extremely useful. In order to reduce the graphic update time required, a process called heterogeneous aggregation (HA) was implemented. The interactor is able to dynamically select the level of detail of the units displayed on the graphic screen. A graphics interface was added to the Force editor that allows the user to build and modify a force according to military organizations with specification to the entity level possible at any level of aggregation. No phenomenology was changed for HA; the war fighting engine still operates at the entity level. Janus was modified to allow deployment and route building for organizations. The large numbers of units did require that some functions not directly related to HA be modified. Even more changes were made after observing users struggle with building large scenarios. Several modifications were made to reduce the labor of the user. The implementation of HA is of broad general use to all Janus users and has been a tremendous benefit to the U.S. Army. Of the many benefits of the JADS project, the addition of this capability to Janus is certainly a significant one.

Prior to the JADS project, TRAC-WSMR used an external program called Janus Distributed Interactive Simulation (JanDIS) which ran on the same host and shared memory with Janus, the combat model program, to communicate with other systems on a network. Practical use in JADS and other distributed projects revealed that the arrangement was too hard to use. The DIS interface was integrated into Janus with a graphical interface for user control of runtime parameters. The firing and detonation PDUs were implemented and tested in the JADS network in coordination with the Tactical Army Fire Support Model (TAFSM).

When Janus is used in a stand-alone exercise, the Janus analyst workstation (JAAWS) program is used as an after action review (AAR) tool. When Janus is part of a distributed application, information from entities not under control of Janus would not be available to JAAWS. Janus Plan View Display (JanPVD) was developed from the JAAWS pattern to display PDUs from all sources. JanPVD can run in the live mode displaying information in real time, or it can run from recorded data to provide replay capability. JanPVD displays position, losses, direct fires, indirect fires, and artillery impacts. The user can select from six different graphs of analysis measures over time. In the replay mode, the user has the additional capability to display movement and routes.

3.1.2 Joint STARS Simulation - VSTARS

The primary interface between the synthetic environment and the Joint STARS system is a simulation of the Joint STARS radar. The phasing of the program required two versions of the simulation, a laboratory version for Phases 1-2 and a version that could be installed on the aircraft for Phases 3-4. The requirements for the simulation are as follows.

- Joint STARS simulation shall enable the mixing of MTI radar virtual entities, terrain, and SAR images in a seamless manner with the actual radar images produced by the E-8C while performing an operational mission.

- Joint STARS simulation will operate within the timeline standards, utilize the same system parameters, and use the same message formats established for the Joint STARS radar system.

- When installed on the E-8C, Joint STARS simulation will provide simulated radar data integrated with live radar data when operating within the ETE synthetic environment.

- For MTI radar reports, Joint STARS simulation will allow operation in three modes: live, where all data are provided by the radar operating system; mixed, where both live and virtual data are provided; and virtual, where all data are provided by the synthetic environment and the Joint STARS simulation. SAR reports will be either real or virtual with no mixing.

In all modes of operation, Joint STARS simulation will permit all of the normal operations performed by the console operator to remain possible, such as target tracking, target type identification, etc., even though most or all of the targets are virtual entities.

When working on a Joint STARS simulation supplemented workstation, the operator should not be able to easily distinguish between live and virtual targets, either visually or as a result of any action normally taken in the course of performing duties.

The ETE team surveyed existing simulations of the Joint STARS radar modes with the following results.

Radar Modes

- None of the existing simulations of the moving target indicator (MTI) mode of the Joint STARS radar duplicated the actual radar characteristics.

- There were no simulations of the synthetic aperture radar (SAR) mode of the Joint STARS radar. The best existing simulation provided a limited number of canned images bearing no operational relevance to the scenario.

- The lack of a SAR simulation precluded support of the fixed target indicator (FTI) mode of the Joint STARS radar.

System Representation

- The existing simulations were either E-8C workstation simulations or ground station module stimulators.

- The existing simulations provided no intersystem interaction and therefore were not designed to operate with actual E-8C components.
- The existing simulations did not provide all the operator functionality.

Intersystem Timelines

- The existing simulations used fixed estimates of the intersystem timelines and therefore were not driven by loading on the system.

Due to the lack of any existing simulation to meet the requirements, JADS initially contracted with Northrop Grumman to evaluate system architectures and develop an engineering design of the selected architecture. The architectural study recognized the primary challenge for the Joint STARS simulation was its integration on the aircraft. Therefore, the study evaluated three candidate architectures for the aircraft version of the simulation.

- Minimize the message traffic on the hardware busses and contain the simulation on the same processing unit as the existing MTI processing.

- Minimize the impact on existing processing by isolating the simulation in an independent processor.

- Increase the fidelity of the simulation or lower the level at which the simulation will be performed.

Each of the three architectures was designed to the level required to evaluate them against the following criterion:

Timeline Impact
Memory Requirements
System Loading
Modification of Existing Software
Modification or Addition of Hardware
Use of Existing Simulations and Models
Level of Simulation
Integration Complexity
Expandibility/Growth

The first candidate was found to have minimal direct impact to the timeline, however, the radar data processor would have increased load and would impact the existing MTI processing. The integration complexity of this architecture was considered large, and the architecture did not support expansion without impacting existing processing.

The second candidate was found to have no impact on the timeline, memory or system loading. This candidate required a reconfiguration of the system configuration to use the spare general purpose computer (GPC). Integration complexity was reduced, and the architecture could be expanded to the maximum capability of the GPC.

The third candidate was expected to impact the timeline as a function of target load. This candidate required the largest development. While the first two candidates limited the level of the simulation to the

MTI report, this architecture would include all sections of the MTI processing up to the signal processor. Integration was considered equivalent to candidate 2. While the expandibility of this candidate was only limited by the capacity of the GPC, the limitation on the number of targets limited the growth of this architecture.

The resulting recommendation was to adopt the second architecture for JADS requirements. Candidate 3 was identified as a future possibility for implementation because of the expanded testing capabilities. Appendix A, Architectural Design Report for the Radar Processor Simulation for the Joint Surveillance Target Attack Radar System (Joint STARS), is the resulting report for this study.

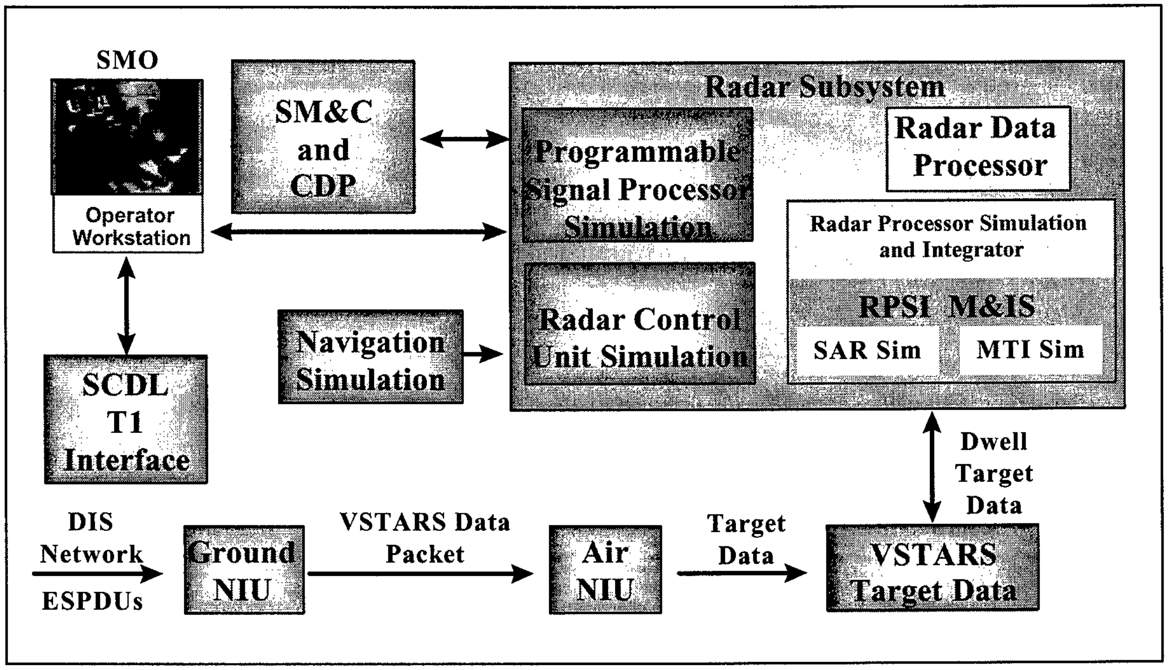
Following the selection of the appropriate architecture, Northrop Grumman conducted an engineering design of the radar processor simulation and prepared a specification of the system-level requirements for the radar processor simulation. Appendix B, Engineering Design Report for the Radar Processor Simulation for the Joint Surveillance Target Attack Radar System (Joint STARS), documents the hardware and software requirements for the radar processor simulation.

During the joint feasibility study (JFS) phase of the JADS JT&E, the ETE team identified the lack of a SAR simulation for the Joint STARS radar to be one of the key risk areas for the ETE test. In parallel with the JFS, the Advanced Research Projects Agency conducted a trade study of 13 existing SAR simulation capabilities in support of the War Breaker program. The War Breaker requirements were similar to the JADS requirements, and the ETE program entered into an agreement with the War Breaker to cooperate on the development of the SAR simulation. As a result of the trade study, the War Breaker identified two candidates as having the potential to be used as a baseline for the development of a SAR simulation. These vendors were requested to submit a rough order of magnitude estimate for the development, and Loral Defense Systems, Goodyear, Arizona, was requested to submit a proposal for a Radar Image Simulation System (RISS) to be based on the XPATCHES simulation developed under sponsorship of Wright Laboratory. The RISS was conceived as a generic SAR simulation which would be capable of simulating SAR capabilities of Joint STARS, Tier II+/III Unmanned Aeriel Vehicles, and the U-2R platforms. During contractual negotiations, the War Breaker program was canceled and JADS ETE was left without a partner for the SAR simulation development. In cooperation with Wright Laboratory, JADS contracted with Lockheed Martin Tactical Defense Systems, the successor of Loral, to develop a Joint STARS specific SAR simulation. This system is called the Advanced Radar Imaging Emulation System (ARIES).

In 1996, JADS ETE, in cooperation with Rome Laboratory, contracted with Northrop Grumman to develop a Joint STARS E-8C simulation, consisting of a radar processor simulator and integrator (RPSI), a distributed interactive simulation network interface unit (DIS NIU) and a data link databus interface unit. This simulation would be developed in accordance with architecture candidate 2 and would be capable of integrating a SAR simulation developed under another contract.

The resulting Joint STARS E-8C simulation is called the Virtual Surveillance Target Attack Radar System (VSTARS), an emulation that represents the radar subsystem of the Joint STARS E-8C in a

laboratory environment. It is composed of the DIS NIU, the RPSI that contains the two real-time radar simulations with necessary databases, and various simulations of E-8C processes.



CDP - central data processor
M&IS - management and integration software
SM&C - system management and control
SMO - system management officer

Figure 3. VSTARS Architecture

The DIS NIU functions are divided between two components. The ground NIU is connected to the DIS network and receives entity state protocol data units (ESPDUs) from the network. It also performs coordinate conversion to the radar's coordinate system and reduces the ESPDUs from the standard 1152 bits to 192 bits. (See Appendix C.) This reduced data packet is then sent to the air NIU where dead reckoning is performed. The splitting of the NIU is required because the RPSI will be integrated into an actual E-8C allowing the mix of live and virtual targets onboard the aircraft. The ESPDU is reduced in size, and dead reckoning is performed by the air NIU in order to reduce bandwidth requirements for the link between the two NIUs.

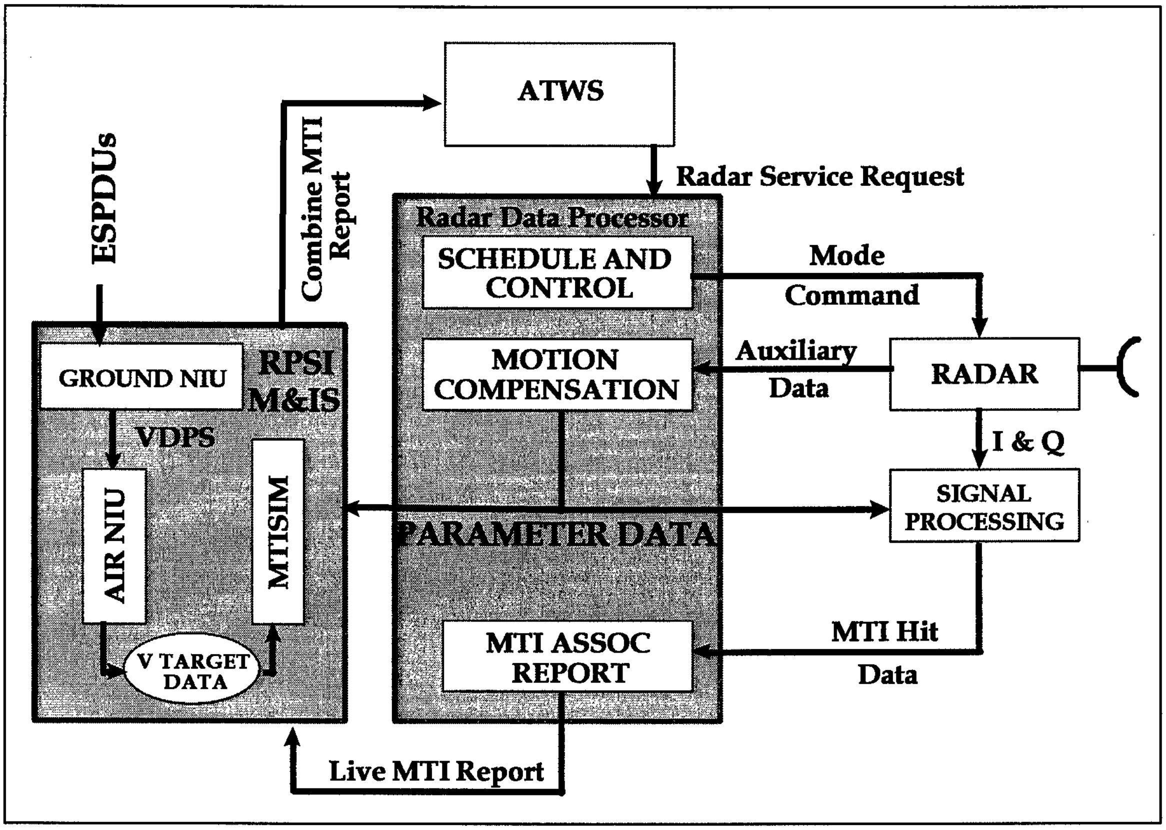
The RPSI completes the concept for mixing real and virtual radar returns. It mixes virtual MTI returns on virtual terrain, and virtual SAR images with actual radar returns without causing any degradation of the aircraft system's capability for handling actual (live) targets. The RPSI is based on the architecture of the aircraft radar subsystem and functions within the actual radar processor software. It is triggered by the same message structures currently used to communicate with and within the radar subsystem; nominally works within the radar subsystem timelines; and outputs its reports in the same formats currently used by the radar subsystem.

When integrated into the radar subsystem of the E-8C, the RPSI architecture is designed to function in three primary modes.

1. All real, where only the aircraft's radar subsystem is providing information on the real environment.
2. Mixed mode, where both the radar subsystem and the RPSI are providing information on the real and virtual environment.
3. Virtual mode, where only the RPSI is providing information on the virtual environment.

The MTI simulation developed by Northrop Grumman and used in VSTARS is based upon an engineering model used during the development of the E-8C radar. As such, it went through many cycles of model-test-model and is considered to be a valid model of the MTI mode of the E-8C radar. It characterizes target probability of detection (Pd) and location accuracy, in the presence of clutter assuming a constant false alarm rate, as a function of key radar system variables that can be implemented in the real-time target detection stream of the MTI radar system.

The simulation receives programmable signal processor (PSP) messages that indicate the limits of the current radar beam footprint (dwell quadrilateral) and determines what portion of the footprint is allowed virtual targets. It then determines which moving virtual targets are located within the virtual portion of the dwell quadrilateral, based upon their latest dead reckoned position. Once the possible target set is determined, Pd is applied and the detected target set is derived. Location error is then applied to the detected targets and the target set is sent to the radar post processor. A false alarm simulation runs whenever the MTI simulation is operating in the 'virtual only' mode. This generates false returns, including meteorological effects, based upon radar system variables. A flow diagram for the MTI simulation is shown in Figure 4.



I&Q - in-phase and quadrature (radar data)　　VDPS - VSTARS data packet

Figure 4. VSTARS MTI Flow Diagram

The SAR simulation, ARIES extends the capabilities of XPATCH target signature modeling, XPATCHES image scene generation, and interfaces with Northrop Grumman's RPSI to provide a complete methodology for the real-time simulation of the Joint STARS SAR mode of operation.

ARIES will be initiated by the receipt of a radar service request requesting a SAR image with an image center point specified within the virtual portion of the ground radar coverage area (GRCA). The GRCA covers thousands of square kilometers, is specified in the mission orders, and is the area scanned continuously by MTI wide area surveillance. It also acts as a limiting area for special radar products such as a SAR image. The virtual portion of the GRCA will be so indicated upon initialization of the RPSI. ARIES, upon initialization of the RPSI, will create three data bases within hardware random access memory (RAM) containing elevation and feature data for the GRCA, and a feature target function library for all the features contained in the feature data base.

Once the center point of the virtual SAR image is known, ARIES will over sample around the center point and extract the elevation data for an area that will exceed the image area coverage. ARIES determines from the contour algorithms if any terrain feature outside the image area will influence the

image area. ARIES will also determine which terrain features exist within the target area. Using this data, ARIES will develop a ground truth point map of the sampled area.

ARIES will wait for the PSP parameter message to arrive before doing any further processing. The PSP parameter message, a product of the actual scanning of the area of interest (AOI) by the radar, contains such information as actual grazing and squint angles, size of imaged area, and other information needed by ARIES to image the AOI. Once the PSP parameter message is received, ARIES will select the actual image area from the ground truth point map and begin applying XPATCHES image generation algorithms to generate the SAR scene. The SAR flow diagram is shown in Figure 5.

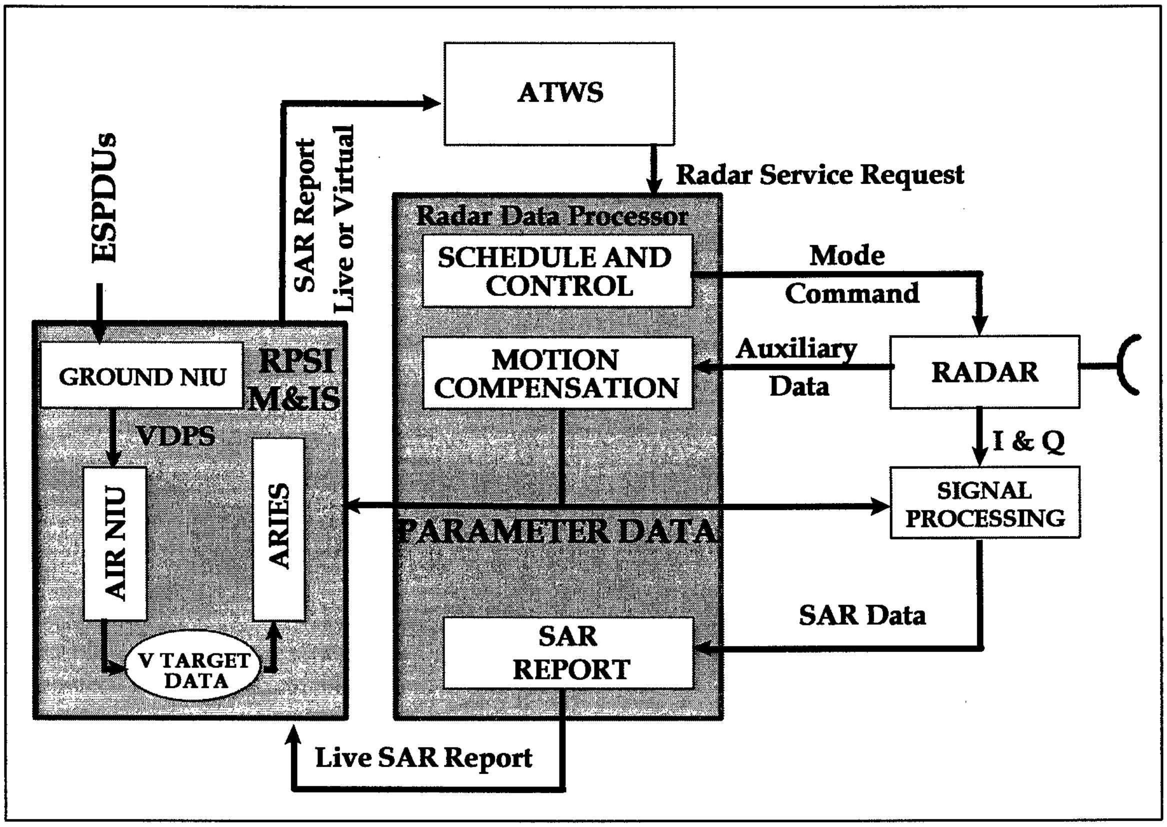


Figure 5. VSTARS SAR Flow Diagram

The RPSI will also receive the PSP parameter message and will use the actual imaged area to determine what virtual targets are located within the AOI. It will then send this target list to ARIES, which will obtain from feature target function libraries the appropriate target image chips for insertion into the SAR image. Moving targets will be displaced, or smeared, within the image as appropriate. Once this is accomplished, the image will be sent to the RPSI for forwarding to the post processor. Timing studies indicate that it will take ARIES up to three times longer, depending on the processor, to generate a SAR image than the real radar. Since the requester has no way of knowing when the SAR mission was initiated, we do not feel that this delay will be noticed.

Both the MTI and SAR simulations allow the radar operators to perform all of their required functions.

The primary difference between VSTARS operating within the laboratory and the RPSI operating on board the real E-8C is the need to simulate the navigation subsystem and certain radar components within the laboratory. These simulations make it possible for VSTARS to function without an E-8C present.

In use, VSTARS must be connected to an operator's workstation, currently the Advanced Technology Work Station, that serves as the interface between the aircraft crew and the radar. VSTARS output can also be sent to the ground component of Joint STARS via a virtual surveillance control data link (SCDL).

Appendices 4 and 5 document the Phase 1 efforts of Northrop Grumman and Lockheed Martin respectively.

3.1.3 Surveillance Control Data Link Interface

Joint STARS consists of two segments: the air segment consisting of the E-8C and the ground segment consisting of a ground station module (GSM) or a common ground station (CGS). These segments are connected via a line-of-sight radio frequency data link called the surveillance control data link. This data link supports the transfer of radar products from the E-8C to the GSM/CGS and allows the GSM/CGS operators to submit radar service requests to the E-8C. Additionally, the data link supports free text messaging between the E-8C and the GSM/CGS.

The initial concept for connecting the VSTARS and the GSM/CGS was to encapsulate the SCDL messages in a DIS message PDU. Upon more detailed research the ETE team discovered the necessary data concerning the SCDL were not releasable, and that the team would be unable to encapsulate the data. The next approach was to transmit the SCDL directly over a wide area network link. In this case, the team discovered they were unable to make the intrusive link into the ground data terminal (GDT) of the GSM/CGS. The final solution for making this connection was to capture the data prior to their transformation into SCDL data and transmit these data between VSTARS and the GSM/CGS. In VSTARS this entailed capturing the data prior to the SCDL process, and in the GSM/CGS the data are bridged from a local area network connection to the military standard (MIL-STD) 1553 databus in the GSM/CGS.

The VSTARS data link databus interface unit consists of a software process within VSTARS that establishes a connection between VSTARS and the GDT 1553 bus interface unit (BIU) at the GSM/CGS. This connection uses the transmission control protocol to establish a reliable communications link via a local area network connected to the VSTARS processor, a secure wide area network link, and the local area network connected to the GDT 1553 BIU.

The interface between the VSTARS data link databus interface unit and the GDT 1553 BIU is controlled by an interface control document between Northrop Grumman and Motorola Communications System Division. (Appendix F)

The GDT 1553 BIU was developed by Motorola Communications Systems Division, Scottsdale, Arizona. Motorola is also the developer and producer of both the GSM and the CGS. The GDT 1553 BIU consists of a Sun SPARC 5 workstation with both Ethernet and MIL-STD 1553 interface cards. The BIU is integrated with the GSM/CGS is such a way that the GSM/CGS operator must establish a SCDL using the normal operational procedures and commands before the BIU will allow the connection via the wide area network.

Appendix G is the software test plan for the GDT 1553 BIU. JADS ETE established a communications link with Northrop Grumman in Melborne, Florida, to support integration among the contractors and testing. The initial test was conducted at the Motorola facility in July 1997 between prototype CGSs and VSTARS. In this test, a data dropout problem was identified which could not be isolated. The decision was made to accept the BIU pending its integration with an operational GSM at Fort Hood, Texas. In February 1998, the GDT 1553 BIU was integrated with two light ground station modules at Fort Hood. The test was successfully repeated during this integration period. We believe the combination of controlling the speed of the data link, a normal function with the actual SCDL, coupled with a stable test environment of operational GSMs, rather than prototype CGSs, solved this integration problem.

3.2 End-to-End Network

The ETE network was designed to be a dedicated network based on commercial communications links using DIS protocols where appropriate. The ETE team developed an engineering process for identifying the requirements for any network configuration considered. As the makeup of the ETE synthetic environment evolved during the planning stages of Phase 1, the ETE team used this process to refine the requirements for the ETE network. We will describe this process in terms of the network integrated at the end of Phase 1.

3.2.1 Network Requirements Analysis

The first step in the process is to conduct a flow analysis of the data required. Each node is examined to identify the data required from other nodes and the data supplied to other nodes. Figure 6 is ETE data flow diagram.

In addition to the PDU and data link data identified in the diagram, each site is connected with a dedicated voice link for test control.

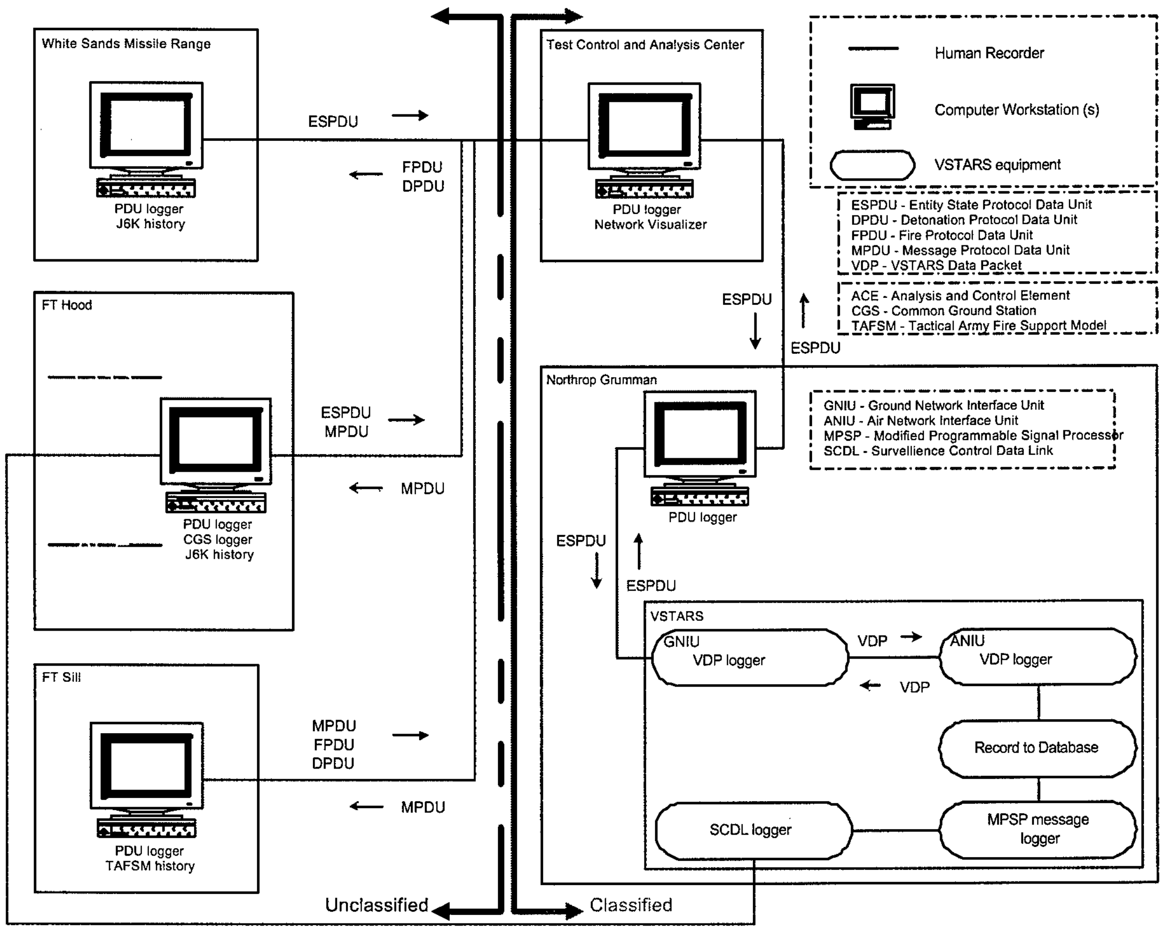


Figure 6. ETE Data Flow Diagram

The second step in the process is to estimate the amount of data required to pass between the nodes. For example, the estimate for the entity state PDUs from WSMR to the TCAC is made using the following calculation:

Assumptions: 9500 entities publishing ESPDUs with a heartbeat of 1 minute
No more than 25% of the entities moving during any second
No more than 1% of the moving entities changing state during any second
ESPDU consists of 1152 bits
PDU protocol overhead is 288 bits

Heartbeat Requirement: 9500 entities / 60 seconds = 158.3 PDUs per second
State Change Requirement: 9500 entities X .25 = 2375 movers
2375 movers X .01 = 23.75 PDUs per second

Total ESPDUs per second: 183 per second

Total bandwidth required: 183 PDUs per second X 1440 bits = 263,520 bits per second
Each flow between two nodes is estimated using similar calculations and the total flow between the two nodes is calculated. Additionally, network management overhead is estimated and added to the total. The resulting estimated requirement for the WSMR - TCAC example is calculated below:

ESPDUs from WSMR	263,520 bps (bits per second)
ESPDUs to WSMR	2,880 bps
Fire PDUs to WSMR	768 bps
Detonate PDUs to WSMR	832 bps
Voice Channel	64,000 bps
Network Management	500 bps
Total Requirement	332,500 bps
Safety Factor (X 2)	665,000 bps

The final step in the process is to determine the appropriate size of the commercial link between the nodes. In general, commercial links are sold as channels each having a 64,000 bps capacity and T carriers consisting of multiple channels, e.g., a T-1 link having 24 channels (1.544 megabits per second). The example above would require 11 channels or a single T-1 link.

The ETE team performed numerous estimates of the network requirements based on varying assumptions and configurations. Based on these various estimates, the requirements for the ETE network showed above were as follows:

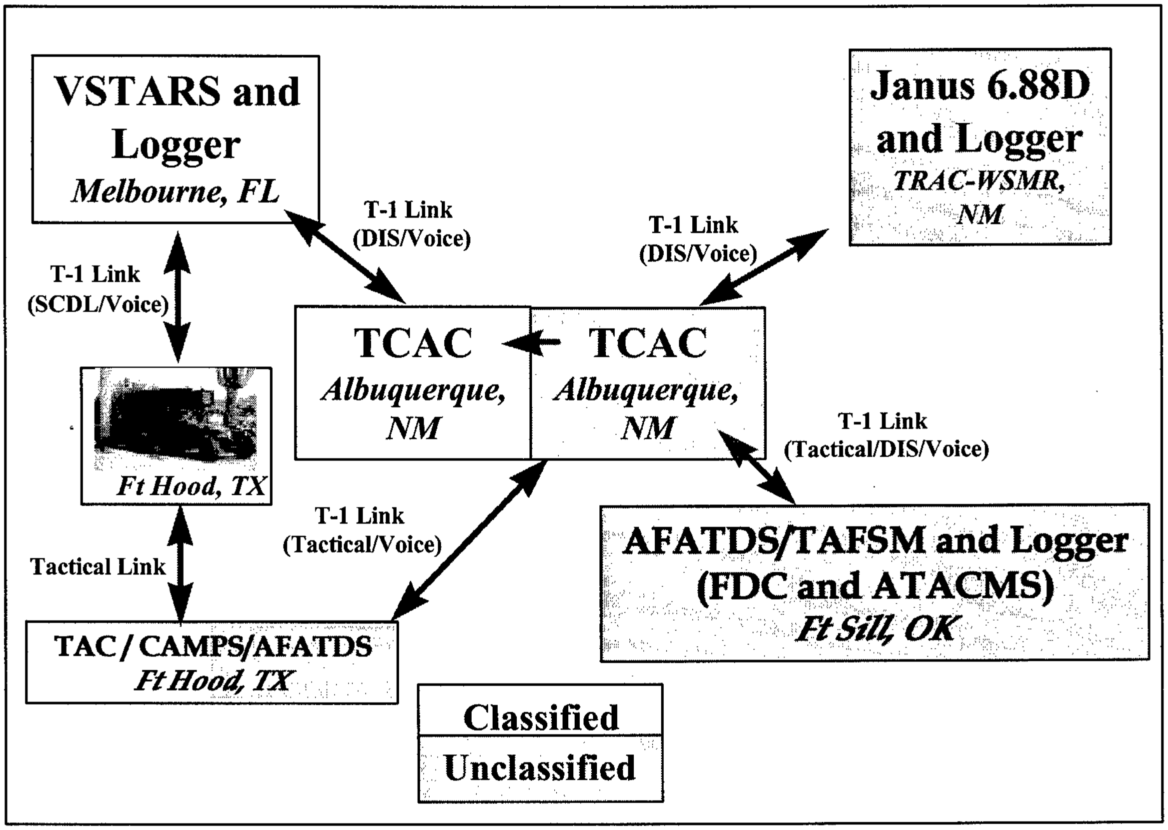
WSMR - TCAC	T-1	1.544 Mbps (megabits per second)
TCAC - Northrop Grumman	T-1	1.544 Mbps
TCAC - Fort Hood	2 channels	.128 Mbps
TCAC - Fort Sill	4 channels	.256 Mbps
Northrop Grumman - Fort Hood	4 channels	.256 Mbps

Although the estimated requirements for three of the links were less than T-1 capacity, we determined during procurement that commercial vendors charged less for T-1 links than for fractional T-1 links. Therefore, all the links for the ETE network are T-1.

3.2.2 End-to-End Network Security

Security presented a problem for the ETE network. The initial concept for the ETE network was for an encrypted network protected at the secret level. As the team coordinated the requirements with the various nodes, we determined that supporting a classified network presented problems for three of the nodes. The Northrop Grumman node was the node which required protection and any connection to this node would also require protection. Through analysis of the data flows identified above, we determined that the only data flowing from Northrop Grumman was a single ESPDU per second which would only be used for test control. Therefore, we determined that if we could establish a security guard or an air gap between the sites desiring to operate at the unclassified level and the TCAC,

Northrop Grumman, and the GSM, we could overcome the problems at these sites. Figure 7 describes the resulting network.



CAMPS - Compartmented All Source Analysis System Message Processing System   TAC - target analysis cell

Figure 7. ETE Network

The initial separation between the unclassified segment and the classified segment was effected by developing an unclassified annex of the TCAC and connecting it with a low to high security guard consisting of a simplex encrypted link. This link allows traffic from the unclassified segment to be passed to the classified segment, but blocks traffic from the classified segment from flowing to the unclassified segment. The other break occurs at Fort Hood. The Compartmented ASAS Message Processing System (CAMPS) is a configuration of the All Source Analysis System (ASAS) which is certified as a high to low security guard. This system is being used in the ETE network to separate the secret-level GSM from the unclassified segment of the network.

3.2.3 End-to-End Network Characterization

The JADS JTF identified network technology as a potential concern or constraint for using ADS for test and evaluation. The JADS evaluation methodology identifies several measures used to evaluate the

network related concerns and constraints. The following measures were evaluated in part or in whole in Phase 1.

M 2-1-2-3 Average and peak bandwidth used by link.
M 2-1-2-6 Percentage of total PDUs required at a node that were delivered to that node.
M 2-1-2-7 Average and peak data latencies between ADS nodes.

The JADS Network and Engineering and Analysis teams in conjunction with the ETE team developed a process for characterization of a network link prior to its integration into a synthetic environment. At Appendix H are the results of characterization tests conducted by Northrop Grumman, WSMR, Fort Hood, and Fort Sill links, respectively. An instrumentation limitation exists in JADS ability to measure average and peak bandwidth for all the ETE links. The particular instrumentation suite used to measure bandwidth utilization is called SPECTRUM. This instrumentation suite is installed in the classified portion of the TCAC and is currently classified secret. Therefore, we cannot use it to measure bandwidth utilization for unclassified links. This limitation is reflected in the data reported below and in the appendices. The tables below summarize the results of these tests.

Table 3. Bandwidth Utilization for Grumman Link

Times Expected Rate (X E.R.)	Rate (PDU/sec)	Number PDUs Received	Bandwidth Utilization (%)
1 X E.R.	100	11859	10
2 X E.R.	200	11858	21
3 X E.R.	300	11853	28
4 X E.R.	400	11847	40
5 X E.R.	500	10492	45

Table 4. PDU Verification Test Results

Location	No. of PDUs Received	No. of PDUs Transmitted	No. of PDUs Out of Order	No. of PDUs > 1 sec.
Grumman	11859	11859	0	0
WSMR	11859	11859	0	0
Fort Hood	11859	11859	0	0
Fort Sill	11859	11859	0	0

Table 5. Stress Test Results (11859 PDUs Transmitted)

Link	Times Expected Rate (X E.R.)	Rate (PDU/sec)	Ping Time (ms) Min/Max/Ave	Number PDUs Received
Grumman	1 X E.R.	100	60/120/61	11859
	2 X E.R.	200	59/90/68	11858
	3 X E.R.	300	59/90/64	11853
	4 X E.R.	400	57/210/79	11847
	5 X E.R.	500	57/840/256	10492
WSMR	1 X E.R.	100	59/61/59	11859
	2 X E.R.	200	41/61/59	11858
	3 X E.R.	300	41/60/45	11853
	4 X E.R.	400	41/61/58	11850
	5 X E.R.	500	41/70/56	11849
Fort Hood	1 X E.R.	100	40/69/59	11859
	2 X E.R.	200	37/60/42	11858
	3 X E.R.	300	50/60/59	11853
	4 X E.R.	400	38/ 61/58	11859
	5 X E.R.	500	37/61/54	11859
Fort Sill	1 X E.R.	100	30/61/58	11859
	2 X E.R.	200	30/60/52	11857
	3 X E.R.	300	30/61/43	11853
	4 X E.R.	400	30/60/36	11859
	5 X E.R.	500	30/84/300	10656

Table 6. No Load Latency Test Results

			Round-Trip Time (ms)		
Source	Destination	No. Packets	Minimum	Maximum	Average
TCAC_Indy	Grumman_Indy	32	57	71	57
TCAC_Indy	WSMR Indy	32	41	44	41
TCAC_Indy	Fort Hood Indy	32	37	77	38
TCAC_Indy	Indy	32	30	40	30

Table 7. Loaded Latency Test Results

Source	Destination	Packet Rate(sec)	Packets Sent/Rec	Round-Trip Time (ms) Min	Max	Ave
TCAC_Indy	Grumman_Indy	.01	320/320	58	163	60
		.005	640/639	58	61	58
		.0025	1280/1279	58	124	58
		.00125	2560/2559	58	167	58
TCAC_Indy	WSMR Indy	.01	320/320	42	45	42
		.005	640/639	42	85	42
		.0025	960/960	42	51	42
TCAC_Indy	Fort Hood Indy	.01	320/320	38	39	38
		.005	640/639	39	55	39
		.0025	960/960	38	76	39
TCAC_Indy	Indy	.01	320/320	31	33	31
		.005	640/639	31	33	31
		.0025	960/960	31	33	31

The results of the network characterization tests indicate the ETE network should meet the performance requirements of the tests with adequate margin.

The stress test results indicated a potential problem with loss of data under stressful situations. Appendix I documents a detailed analysis of this problem performed by the JADS Network and Engineering team and a field engineer from Network Equipment Technologies, the developer and manufacturer of one of the routers used by JADS in their networks.

The local area network (LAN)/wide area network (WAN) Exchange (LWX)/Cisco router investigation had five objectives:

1. Verification/validation of the problems witnessed by JADS Network and Engineering
2. Comparison of the performance gains/losses of external router configurations
3. Effects of altering internal software configuration (buffers, hold queues, etc.)
4. Effects of using a hybrid routed/bridged network
5. Effects of a completely bridged network

The LAN/WAN Exchange (LWX) Release 3.01 is a general purpose router/bridge integrated into the Integrated Digital Network Exchange (IDNX) platform. It provides internetwork connectivity between LANs over WANs through IDNX/ 90, /70, /20, and /Micro 20 IDNX nodes. The LWX is the primary router used in the ETE network. The investigation also evaluated the performance of two versions of routers from Cisco. All the routers evaluated use equivalent software from Cisco.

Throughout all the tests the broadcaster, a Silicon Graphics, Inc. (SGI) Indy workstation, used a file that consisted of 11,859 DIS ESPDUs. The SGI workstation broadcasted the PDUs on its LAN as user datagram protocol (UDP) packets. The LWXs were configured to forward these broadcasts through the network. Each entity state PDU was 144 bytes in length. The internet protocol (IP) datagram produced was 152 bytes in length. All this was verified using a network general sniffer protocol analyzer on the Broadcaster subnetwork.

At the distant end, the logger, also an SGI Indy workstation, listened for UDP broadcasts and counted the number received. The difference is the number of packets dropped within the network.

The primary results of the investigation are as follows:

- The use of UDP - an inherently unreliable transport mechanism - is not always a suitable choice of transport for data that needs a high level of reliability. The transmission control protocol (TCP) is better suited for reliable transport since it uses sequencing and acknowledgments, but at a cost of increased latency - which was not tested. Also, the use of multicasting or unicasting would take advantage of the fast switching capability of all the routers tested.
- The use of broadcast-based networking has an adverse effect on the network. Routing this traffic adds one additional layer of processing (especially when the broadcasts are process switched) and creates multiple copies of each datagram in order to forward it to multiple network subnets, thus, congesting the network with broadcast traffic. When routing broadcast traffic, the network should be designed as flat as possible.
- There were definitive "break points" where the processors could not handle anymore packets. This was true on every platform tested.
- During the testing, we did notice that there were drops on the hold queue, missed buffer requests, and fallbacks on the interface buffers. To remedy this we added to the hold queue length and increased the number of permanent big buffers. The actual number of successful packets sent never rose above the initial ceiling. In other words, the addition of buffers and increasing the hold queue did not affect, in any way, the speed at which the processor process switched the packets.
- It is our best judgment that the limitation is with the router's processor handling UDP broadcasts. With UDP broadcast traffic, all packets are process switched. With unicast and multicast traffic, the router is capable of fast switching most of the packets. Routers gain efficiencies when they are capable of caching routes for packets.

The investigation concluded that with our current network configuration using routing between subnets, we were limited to an aggregate of 400 packets per second through any of the routers. This limitation is adequate for the planned ETE tests. If further studies identify the requirement for an aggregate throughput in excess of 400 packets per second, switching from routing to bridging between the subnetworks would allow up to 800 packets per second.

3.3 Data Management and Data Analysis

Another potential concern or constraint for using ADS for test and evaluation is the impact of ADS on data management and data reduction. In addition to system under test data, an ADS implementation must instrument the synthetic environment to collect data on the environment and analyze these data to determine the impact of the ADS environment on the system under test. The JADS evaluation methodology identifies several measures used to evaluate the data management and analysis related concerns and constraints.

M 2-2-1-1 Degree to which ADS nodes provide for collection, data entry, and quality checking of pre- and post-trial briefing data.
M 2-2-1-2 Adequacy of relevant test data storage at ADS nodes.
Subobjective 2-3-3 Develop and access methodologies associated with data management and analysis for tests using ADS.

3.3.1 Synthetic Environment Data Collection

The primary instrumentation of the ETE synthetic environment are data loggers at each node to collect and time stamp all PDU data transmitted and received at the node. The ETE team planned to install dedicated data loggers at each location to ensure common data formats and file formats for each site. Early in the JADS program, the planned approach for all tests using DIS was to use a logger application available from the U.S. Army Simulation, Training, and Instrumentation Command (STRICOM). The testing of a C4ISR system such as Joint STARS required running operational scenarios over long periods of time, resulting in large (approximately 600,000 PDUs) data sets.

A limitation of the STRICOM logger was discovered during a line test between TRAC-WSMR and the TCAC. The STRICOM logger allocates 256 segments per file. As the segments fill to capacity the STRICOM logger closes the file and ceases recording information. A proposed solution to the 256 segment limitation was the use of sequential files. The logger would recognize when a file was meeting the limitation, close the file and open a new sequential file. However, there existed the possibility that information might be lost during the process of closing one file and then opening a sequential file. An alternative to the STRICOM logger was the Janus logger, an application distributed with Janus that allowed the collection and replay of PDUs. However, the Janus logger was designed to time stamp to a one second accuracy.

The ETE team decided to develop a logger test to examine the strengths, weaknesses, and limitations of the STRICOM and Janus loggers. This test focused on two issues:

1. What is the impact of using sequential files?
2. Is the time stamping of the Janus logger sufficiently accurate for analysis?

A test bed was established in the TCAC consisting of an Janus system providing the source of the PDUs, a Janus logger, a STRICOM logger set to a 50 segment limitation, and a STRICOM logger set to a 250 segment limitation. The scenario was set to produce approximately 600,000 PDUs over a two-hour test.

The conclusions from this test are as follows:

STRICOM Logger: Segmentation at either 50 or 250 segment size is usable. The opening and closing of sequential files did not disrupt the recording of PDUs. The file sizes should be chosen to enhance data sampling and analysis. The test uncovered a potential problem with the STRICOM logger. During one of the runs, one of the STRICOM loggers experienced a loss of 151 PDUs in a single block. Although we were unable to identify the specific source of the loss, we suspected that some other process commenced which placed a demand on the processor resulting in the loss of the PDUs.

Janus Logger: The Janus logger does not time stamp at the required accuracy to allow analysis of PDU latency and is therefore only useful for its playback capabilities.

The conclusions of the logger evaluations led JADS to develop the JADS logger. The JADS logger was designed with three objectives:

1. High degree of time stamp accuracy.
2. Minimized processor load.
3. Flexible playback capability

The JADS logger was designed as two processes. The first process is a high-priority process that time stamps the PDU upon receipt. The second, a low-priority process, logs the PDUs when the processor is not busy. This ensures an accurate time stamp. The JADS logger provides users with a very high degree of accuracy with respect to log time (received time) of PDUs (typically better than 1 millisecond).

The JADS logger foregoes graphics interfaces to minimize process load. It uses a simple command line interface, and in real time, displays the number of PDUs received and the PDU rate each time it writes a block of PDUs (typically about 500 entity state PDUs) to disk. Because the logger has a command line interface, the user can remotely log in (rlogin), start the logger as a background process and log out of the workstation without terminating the logger application. This option keeps network traffic to a minimum while performing the logging function at a remote location.

JADS also developed the JADS player, a playback capability that operates in two modes: a speed mode where the operator identifies a multiplier to control the speed of the playback, and a rate mode where the operator designates the numbers of PDUs per second to be played. Additionally, in conjunction with the JADS analysis toolbox, the player can be directed to start the playback at any log time.

The JADS logger/player meets all the requirements of the ETE test and provides a simple and reliable data collection and data analysis tool.

3.3.2 Synthetic Environment Data Analysis

In addition to the logger tools, JADS developed various analysis tools for analysis of the PDU data. The tools have been integrated into (can all be called up from) a single tool, the JADS analysis toolbox. The toolbox provides users with a single interface to the software routines developed by JADS. These tools provide for real-time viewing of PDU data, and for post-test, quick-look analyses using logged PDU data.

The JADS analysis toolbox provides a point and click interface to the various JADS analysis routines. The routines available from the toolbox menu are the following:

- Monitor - 3-D Display: A graphical 3-dimensional (3-D) display of up to 3 entities that displays latitude, longitude, and altitude in real time is provided.

- Monitor - PDU Statistics and/or PDU Latency: The following PDU statistics are provided by the PDU statistics display:
  the total number of PDUs received,
  the PDU (receive) rate,
  the number of entities received, and
  the number of each type of PDU received.
  A plot of PDU latency (received time - PDU creation time) in real time is also available.

- Analyze - Quick-Look: The JADS quick-look analysis tool provides analysts with a point and click means of obtaining mission, PDU, and logger performance data visualizations for DIS exercises. Visualization is provided for four categories of data:

  - Mission Visualization: Present support is for 3-D plots of up to 3 entities, e.g., a shooter, target, and missile, for either the total mission or just during the flyout, and either static or animated.
  - Latency Data Visualization: Plots of PDU latency {from PDU creation to time received}, from logger to logger, for all entities as well as for individual entities can be created. Also, a latency statistics tabulation is available that enumerates the minimum, maximum, and average latency for each entity, each test, and each logger.
  - PDU Performance Visualization: Plots of the number of PDUs received per second of PDU time and the number of PDUs per second of log time for each entity as well as for individual entities are created. Also, a PDU statistics tabulation is available that enumerates the number of PDUs, the number of duplicate PDUs, and the number of PDU dropouts, for each entity, each test, and each logger.
  - Logger Performance Visualization: Plots of log time difference between successive received PDUs for each entity as well as for individual entities are created.

The quick-look analysis tool allows the user to select multiple sets of trials, loggers, and entities and then sequentially presents the selected plot data for review, formatting, and/or printing. Thus, a summary analysis package can be prepared in a short time. The quick-look analysis tool is used in conjunction with the JADS logger which records (logs) DIS PDUs during an exercise.

- Analyze - General Plots: The JADS general plots tool provides for generalized plotting of data from a file. Plots of any of the supported PDU parameters (Entity ID [identification], Log Time, PDU Time, Latitude, Longitude, or Altitude versus another) may be made.

- Dump - Select Entity Parameters: Dumps any to the following selected parameters into a text file from a log file:

  Entity ID
  PDU Time (milliseconds)
  PDU Timestamp (milliseconds - using all 32 bits with each bit as one millisecond)
  Latitude (degree)
  Longitude (degree)
  Altitude (feet)
  North Velocity (feet/second
  East Velocity (feet/second)
  Down Velocity (feet/second)
  X (meters, geocentric)
  Y (meters, geocentric)
  Z (meters, geocentric)
  X Velocity (meter/second)
  Y Velocity (meter/second)
  Z Velocity (meter/second)
  X Acceleration (meter/second/second)
  Y Acceleration (meter/second/second)
  Z Acceleration (meter/second/second)
  Phi (radians)
  Psi (radians)
  Theta (radians)
  Pitch (radians)
  Roll (radians)
  Yaw (radians)
  Pitch Rate (radians/second)
  Roll Rate (radians/second)
  Yaw Rate (radians/second)
  UTM Northing (meters)
  UTM Easting (meters)
  UTM Zone

- Dump - Split File: Splits a log file into a smaller file log file based on user provided log start and stop time.

- Dump - Count PDUs: Provides a tabulation summarizing the following:

  Number of PDUs,
  Number of entity state PDUs,
  Number of data PDUs,
  Number of detonation PDUs,
  Number of fire PDUs,
  Number of start PDUs, and
  Number of stop PDUs.

- Dump - Display Time: Provides a tabulation that displays log time and PDU time in the following formats:

  Log timestamp (seconds since 1970 and microseconds)
  Log time (milliseconds since midnight)
  Log time (hh:mm:ss.sss)
  PDU timestamp (milliseconds past the hour)
  PDU time (milliseconds since midnight)
  Delta PDU time (time between PDUs)
  Latency (log time - PDU time in milliseconds)

- Dump - Moving Entities: Provides a listing for each minute of log time the following data are provided:

  Starting log time
  Ending log time
  Starting PDU time
  Ending PDU time
  Number of PDUs
  Number of movements
  Number of entities that moved

These tools were developed using a foundation of C, C++, Motif, X-Windows, and gnuplot and are transportable to a variety of machines.

The very large data sets and the large numbers of entities associated with the ETE tests required significant modifications to the quick-look and real-time analysis software.

The major modifications were the following:

- Entity Selection: For each desired analysis display, the quick-look program provides the analyst with the capability to select a set of tests (for a given mission/day), a set of log files and, for some analyses, a set of entities. The desired tabulations or plots are displayed sequentially for the

selected tests, logs, and entities, and with each display the user is given the option to vary the format, print, or display a histogram. This ability to select a set of data for which given analysis displays are desired greatly facilitates processing missions that have many tests and many loggers. Previously, the quick-look program read through each selected log file to find all of the different entities that were used so they could be displayed to the analyst for selection. This worked fine when the files were kilobytes in size and the numbers of entities were small, i.e., less than 10. However, for the ETE tests, the files approached 100 megabytes in size, and the numbers of entities were up to 10,000. Thus, the previous program would have to read 100 megabytes, 10,000 times to make sure all of the entities were identified. This would have taken hours before the available entities in the selected logs could be displayed to the user for selection. Even reading through the very large file once took several minutes. Thus, an alternative approach was selected.

The selected approach was to process the log files once for the entities (and for the start and stop PDU and log times – other data needed by the analysis programs that would have required reading through the entire file each time) and to save these data in a companion .stats file. Thus, establishing the entities within a log file (or the earliest and latest PDU or log time) was a simple matter of reading the very short companion .stats file.

- Entities Selection: Again, due to the large number of entities, a method was needed whereby the identification of entities would not be a long, long list of integers. Thus, the handling of selected entities was modified so that the user is shown and can identify entities using the following example string notation

  1-50, 501-600, 9001-9050

  This string identifies 200 entities that the analyst wants included in the analysis. Similarly, the notation is used in the .stats files to tell the analyst (and the software) which entities are included in the log file. It greatly reduces the task of identifying entities, albeit with a minor increase in software workload.

- Data Calculations: Previously, the quick-look program read the PDU data needed for calculation into data arrays. The array sizes for the System Integration Test were less than 5,000, i.e., the number of PDUs for any given test were less than 5,000. The data included entity number, log time, PDU time, latitude, longitude, and altitude. Thus, the total array storage for a given test logger was approximately

  5000 pdus * 6 parameters/pdu * 8 bytes / parameter = 240,000 bytes.

  For ETE, the number of PDUs exceeded 400,000. Thus, the memory that would have been required to keep the data in memory would have exceeded 19 megabytes for a given test logger. Given all the other memory requirements of the quick-look analysis program, this was prohibitive. Thus, it was decided to change all of the data processing routines to accomplish their tasks without using data arrays, i.e., read the minimum data required from a file to accomplish a calculation (at

most this meant two or three PDUs), and then write the results to another file for further processing or for display. The result is software insensitive to the size of the data files insofar as calculations are concerned.

- Entity Number: For previous tests, the entity identification was maintained as a unique number among all the sites, i.e., there was only one entity 3. For ETE, as would be expected in a large-scale DIS exercise, the entity identification was not unique. The entity identification data, i.e., the site ID, host ID, and entity ID combination was unique, so that unique entity numbers could be established based on all three fields. This was accomplished for both quick-look and real-time analysis programs.

3.3.3 Data Management and Analysis Summary

The primary challenge of an ADS test of a C4ISR system is the potential for a large ADS synthetic environment data sets and the use of large numbers of entities. During Phase 1, JADS began to gain insight into some of the problems with data management and data analysis; however, the development and refinement of data management and data analysis tools will continue through future phases of the ETE test.

An equally important area for investigation in future phases will be the impact on system(s) under test data management and data analysis tools. The ADS synthetic environment provides the capability to test multiple systems simultaneously, both individually and to determine impacts of one system upon another system. The nature of C4ISR will require such tests to be run over longer periods of time and will produce large data sets requiring improved data management and analysis techniques.

4.0 Lessons Learned

4.1 Technical Lessons Learned

4.1.1 Data Transport Reliability Considerations

The use of user datagram protocol (UDP) - an inherently unreliable transport mechanism - is not always a suitable choice of transport for data that needs a high level of reliability. Routers and bridges used to connect subnetworks are the primary source of lost data in networks using UDP. The use of UDP forces routers to inspect each packet since it was a broadcast and forward it onto each interface. This activity is known as process switching. Since every packet sent is process switched, there is a limit to the number of packets successfully received when a node floods the network. Testing of several routers confirmed there are definitive "break points" where the router processors cannot handle additional packets.

Routing UDP traffic adds one additional layer of processing (especially when the broadcasts are process switched) and creates multiple copies of each datagram in order to forward it to multiple network subnets, thus, congesting the network with broadcast traffic. When routing broadcast traffic, the network should be designed as flat as possible. Additionally, any routers used should be tested to determine their specific break point.

Bridging UDP traffic precludes the need to process switch each packet and allows the routers to use multicasting or unicasting techniques and take advantage of faster switching capability. This increases the aggregate number of packets a router can reliably transfer.

If reliable transfer of data is required, the transmission control protocol (TCP) is better suited for reliable transport since it uses sequencing and acknowledgments, but at a cost of increased latency.

4.2 Programmatic Lessons Learned

4.2.1 Value of Systems Engineering Process

The development of an ADS synthetic environment for test and evaluation is a challenging activity. The developer must integrate the system(s) under test technology, networking technology, simulation technology, and instrumentation technology into an environment. The activity requires a multifunctional team of personnel to derive the functional and performance requirements, acquire and/or develop the components, and integrate the environment.

The systems engineering process is used throughout the services and industry as an integral process in the development of a system. The process is reiterated during each acquisition phase, and whenever a technical change is initiated or needed, to provide progressive definition of the system. From the beginning of the JADS Joint Feasibility Study through Phase 1, the JADS ETE team has used the

process to define and refine the ADS synthetic environment and the components in the environment. Figure 8 is the Defense Systems Management College's depiction of this process.

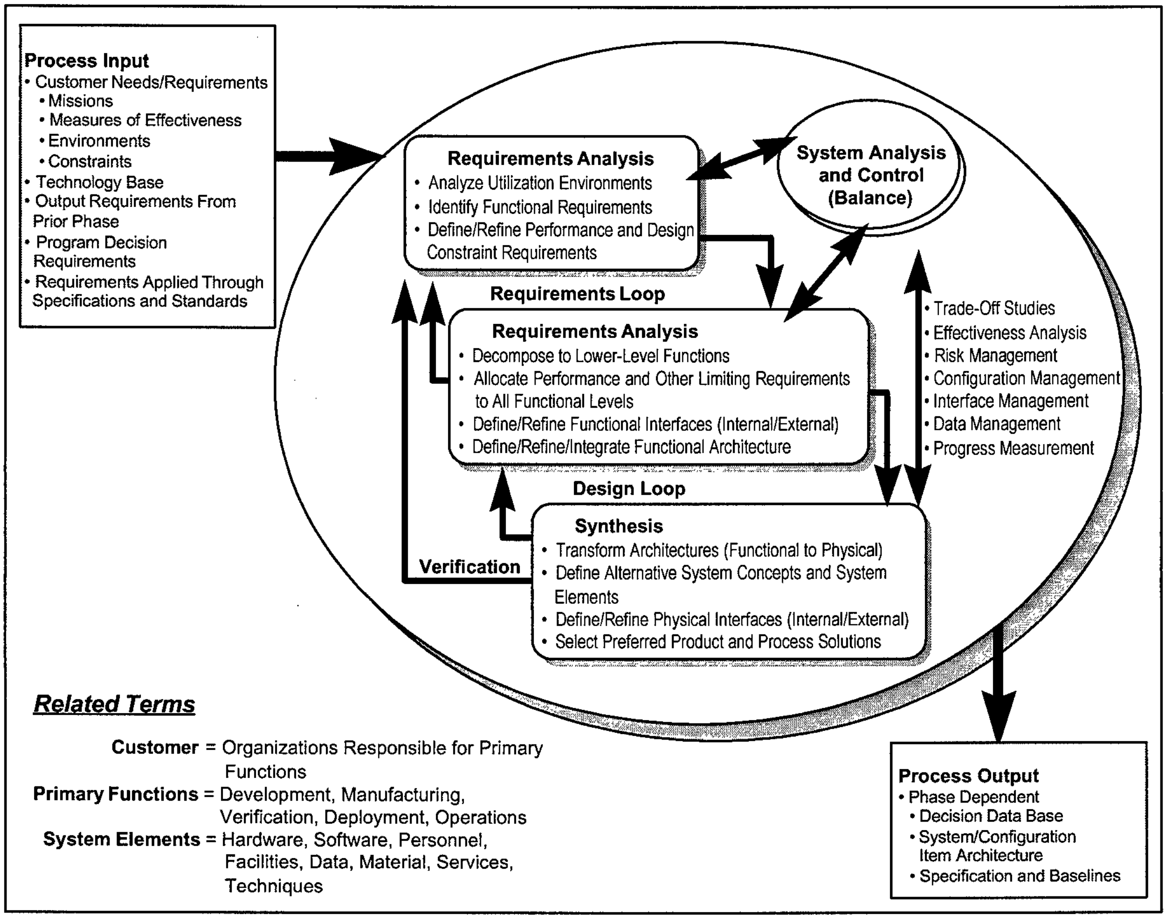


Figure 8. Systems Engineering Process

Requirements Analysis: The customer's requirements are derived/defined/refined and integrated in terms of quantifiable characteristics and tasks that the environment must satisfy. For each requirement, absoluteness, relative priority, and relationship to other requirements are identified. The impact of the requirements is analyzed in terms of mission, environment, constraints, and measures of performance. Impacts are continually examined for validity, consistency, desirability, and attainability. The output of this analysis is the functional (what) and performance (how well) requirements for the environment.

Functional Analysis/Allocation: Through a functional decomposition all primary environment functions and subfunctions are progressively derived/defined/refined to determine the actions/tasks an item must perform to satisfy customer needs. Decomposition continues until all performance requirements are allocated and all functional relationships are determined.

Synthesis: Allocated requirements are satisfied through a bottom up, progressively integrated design/synthesis of process and product alternative solutions. Internal and external interfaces are analyzed, trade-offs made, and a set of design requirements are established. As design requirements are established, verification ensures that all associated functional and physical interfaces and functional and performance requirements are satisfied. The resulting set of design requirements provides the basis for selecting, developing, and integrating the components of the ADS environment.

System Analysis and Control: Throughout the requirements analysis, functional analysis/allocation, and synthesis subprocesses, cost, schedule, performance and risk are balanced to provide an environment that is affordable, suitable, and effective. A variety of analysis and control tools are available to evaluate design capabilities, to determine progress in satisfying technical requirements and technical program objectives, to formulate and evaluate alternative designs/courses of actions, and to evolve the environment to satisfy customer needs.

JADS has learned a key lesson: ADS is not, as some would claim, a "plug and play" technology. Developing an ADS environment requires a disciplined process to integrate the various technologies and functional disciplines into a usable whole. JADS believes the systems engineering process is a proven methodology which can be successfully applied to this challenge.

5.0 Future Activities

Phase 2 of the End-to-End Test consists of planning, preparing, and conducting a developmental test activity using some of the components developed in Phase 1 and planning, preparing and conducting an operational test activity.

5.1 Scenario Development

Each test activity requires the development of one or more scenarios designed to meet the objectives of the specific test activity. Scenarios developed for developmental testing are based on the system specifications of the system under test and require careful analysis and testing to ensure they meet the objectives of the test. Scenarios developed for operational testing are based on a large scale scenario and are focused more on operational realism rather than specification accuracy. JADS will develop 2 scenarios for verification and validation, 12 scenerios for developmental testing, and TRAC-WSMR will make up to nine scenarios for operational testing. Operational test scenarios will be based on an expanded version of a U.S. Army Test and Experimentation Command (TEXCOM) scenario, The Road to War, that TEXCOM uses to test components of the Army Tactical Command and Control System. The overall scenario is 128 hours and JADS has selected nine 6-hour vignettes from the scenario to be implemented in Janus.

5.2 Terrain and Feature Database Development

The SAR simulation developed in Phase 1 requires a highly detailed map of the terrain and features on the terrain to develop high quality images. The basic capabilities of the digital terrain elevation data (DTED) and digital feature analysis data (DFAD) databases developed by the National Imaging and Mapping Agency have neither the quality nor the resolution to meet the requirements of the simulation. JADS will apply Geographical Information System (GIS) technology to the products to correct errors and enhance the data using information on 1:50,000 and 1:100,000 maps. The resulting databases will be used both for the SAR simulation and to provide higher quality terrain maps for Janus.

5.3 Verification, Validation, and Accreditation (VV&A)

VV&A are key aspects of the Phase 2 effort. A verification and validation plan was developed during Phase 1 which applied the principles of the DIS Nine-Step VV&A Process and the DoD VV&A Process into a VV&A process for JADS ETE. In Phase 2, this plan will be executed, resulting in a synthetic environment accredited for use in the JADS ETE operational test at the end of Phase 2.

5.4 Developmental Test

Phase 2 developmental testing will be conducted in conjunction with testing of system upgrades by Northrop Grumman. Northrop Grumman is preparing an update to the E-8C software which includes improvements to the automatic tracker function of the operations and control subsystem. Previous

testing of the tracker has been performed with medium fidelity simulation and multiple flight tests. Northrop Grumman has provided specifications for 12 scenarios which are designed to test all the tracker requirements. JADS will implement these scenarios in Janus and provide log files of the scenarios to Northrop Grumman. Northrop Grumman will use the log files and the JADS player tool developed in Phase 1 to test the automatic tracker. JADS will observe these tests and collect information from Northrop Grumman relative to the utility of the capability.

5.5 Operational Test

Phase 2 will culminate with an operational test which uses the entire ETE synthetic environment and includes constructive, virtual, and live participants. The operational test is designed to evaluated the utility of the environment to support early operational testing or assessments using a laboratory environment. Janus will be used to provide constructive targets for the Joint STARS sensor being simulated by VSTARS. Radar reports from VSTARS will be sent to E-8C workstations in a Northrop Grumman laboratory and will be sent to a ground station module (GSM) located at Fort Hood, Texas, using the SCDL interface. The GSM will be in support of a subset of the analysis and control element (ACE) who will merge Joint STARS data with other intelligence sources to analyze the battlefield and to nominate targets for the Army Tactical Missile System (ATACMS). These nominations will be sent to the Depth and Simultaneous Attack Battle Lab at Fort Sill, Oklahoma, where doctrinally correct artillery command and control will be simulated and eventually a simulated missile will be fired at the target. Messages describing the firing and detonation of the missile will be sent back to Janus for assessment of damage on the battlefield. Data will be collected which supports the evaluation of operational measures of effectiveness to allow JADS to evaluate the utility of the environment to support operational testing.

APPENDIX A

Architectural Design Report

for the

Radar Processor Simulation

for the

Joint Surveillance Target Attack Radar System

(Joint STARS)

ARCHITECTURAL DESIGN REPORT FOR THE RADAR PROCESSOR SIMULATION FOR THE JOINT SURVEILLANCE TARGET ATTACK

RADAR SYSTEM (JOINT STARS)

EST NO. 14
RADAR PROCESSOR SIMULATION (RPS)

DOCUMENT NO. JADS-RPT-001
DATA ITEM NO. Q002
March 1996

CONTRACT NO. F19628-94-C-0040-P00023

Prepared for:

Department of the Air Force
Headquarters Electronics System Center
Hanscom Air Force Base, Massachusetts 01731

Prepared by:

Grumman Aerospace Corporation
2000 W. Nasa Blvd.
Melbourne, Florida 32904

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1 Purpose

This document is intended to report on the results of a study conducted to determine and evaluate candidate architectures for the RADAR Processor Simulation (RPS) for the JOINT-STARS system, for the purposes of integrating JOINT-STARS into a Joint Advanced Distributed Simulation (JADS) environment. A typical JADS environment is shown in Figure 1-1.

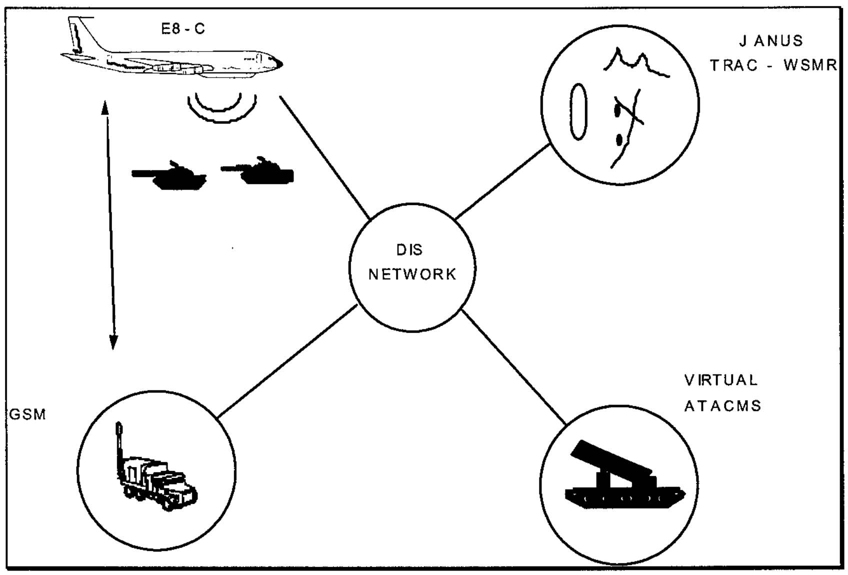

Figure 1-1 Typical JADS Environment

The general concept of operation for the JSTARS system within such an environment is as follows:

- The JSTARS aircraft will fly over a government controlled facility (such as Ft. Irwin)
- A small area will contain controlled targets, tanks, trucks, etc.
- A target/war simulation such as JANUS will be operating at a government facility such as White Sands Missile Range (WSMR) generating virtual targets and issuing Protocol Data Units (PDUs) on the Distributed Interactive Simulation (DIS) network
- The RPS will receive the virtual target information, from the DIS network via entity state PDUs and supply virtual target RADAR reports combined with the live target RADAR reports

The block diagram for the JSTARS system is shown in Figure 1-2. The JSTARS system consist of five subsystems the Operations and Control Subsystem, the Data Link Subsystem, the Communications Subsystem, the RADAR Subsystem, and the Aircraft Subsystem. The focus of this study will be on the RADAR Subsystem which is shown in more detail in Figure 1-3.

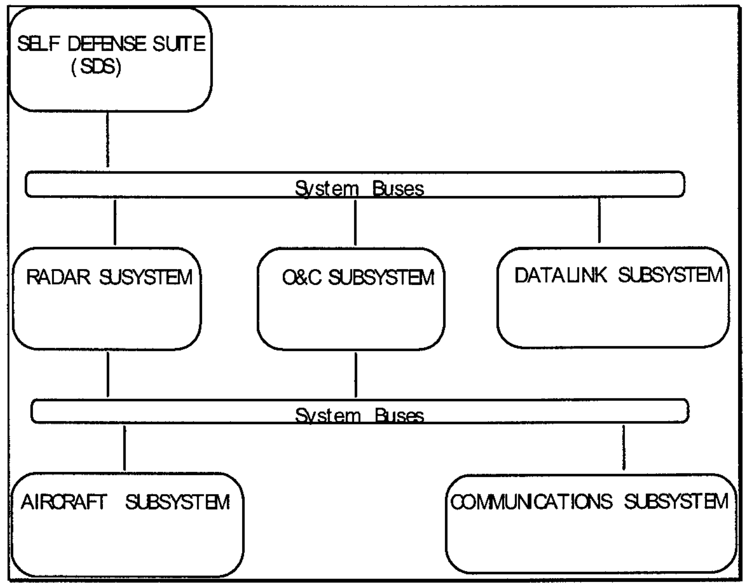

Figure 1-2 JSTARS System Block Diagram

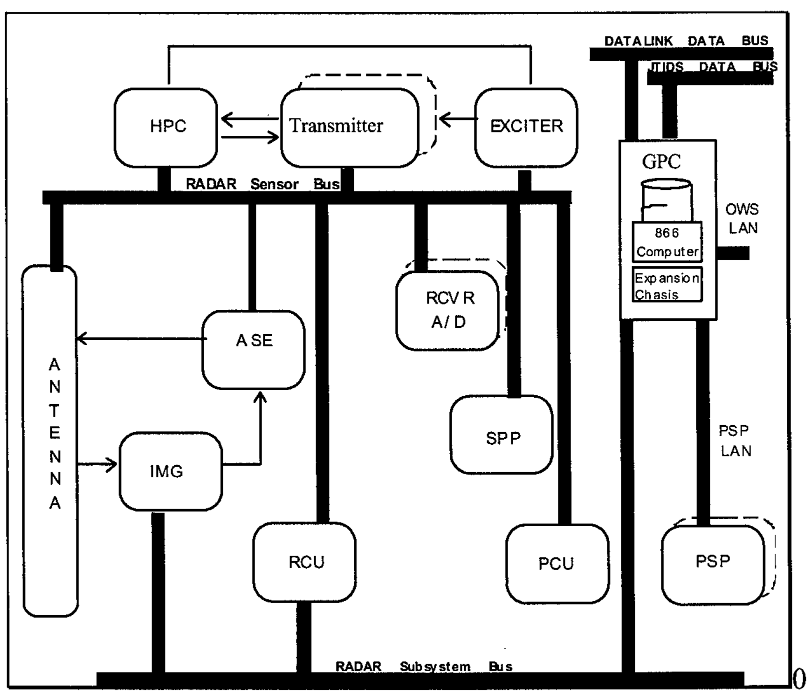

Figure 1-3 RADAR Subsystem Hardware Block Diagram

The RADAR subsystem includes a RADAR Data Processor (RDP) which is a VAX 866 General Purpose Computer (GPC), a RADAR Sensor and Programmable Signal Processors (PSPs). The RDP is

used to control the sensor and process data received from by the sensor. The RADAR sensor is comprised of the Line Replaceable Units (LRUs) required to position the Antenna, generate the Radio Frequency (RF) signal, amplify and radiate the RF signal, receive the reflected signal and process the signal to a video level. The video data in the form of In-Phase and Quadrature (I&Q) data is further processed for target detections in the PSPs and RDP.

Some candidate architectures presented in this report will use a computer designated as the ``Spare" GPC. This GPC is contained in the O&C Subsystem which is shown in Figure 1-4. The ``Spare" GPC has access to the same data buses as the RDP, which makes it a prime candidate for performing functions similar to the RDP.

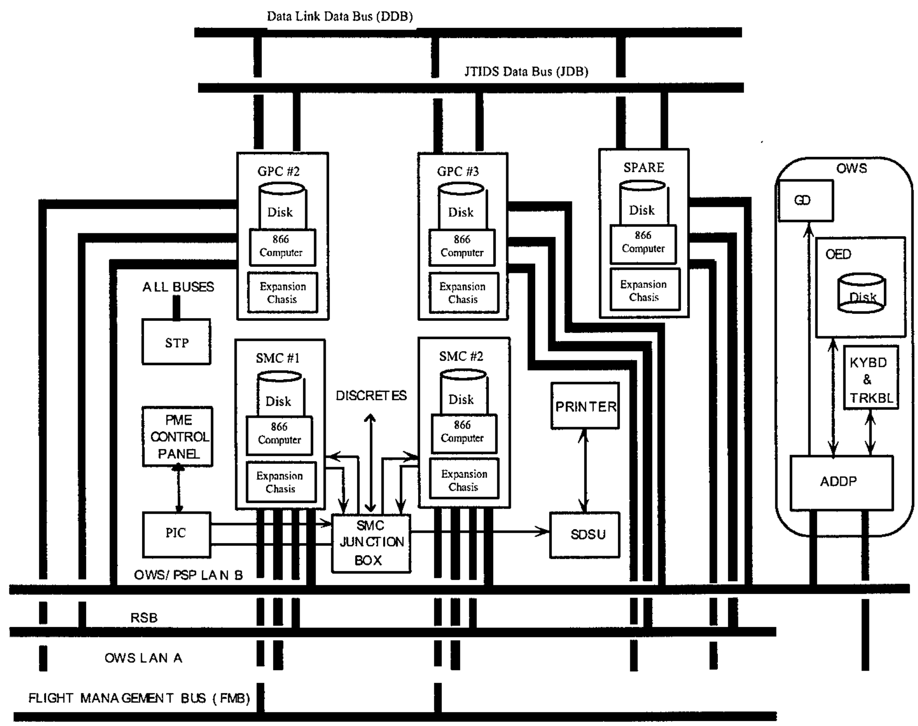

Figure 1-4 O&C Subsystem Hardware Block Diagram

The RADAR processing functional allocation to the hardware components is shown in Figure 1-5.

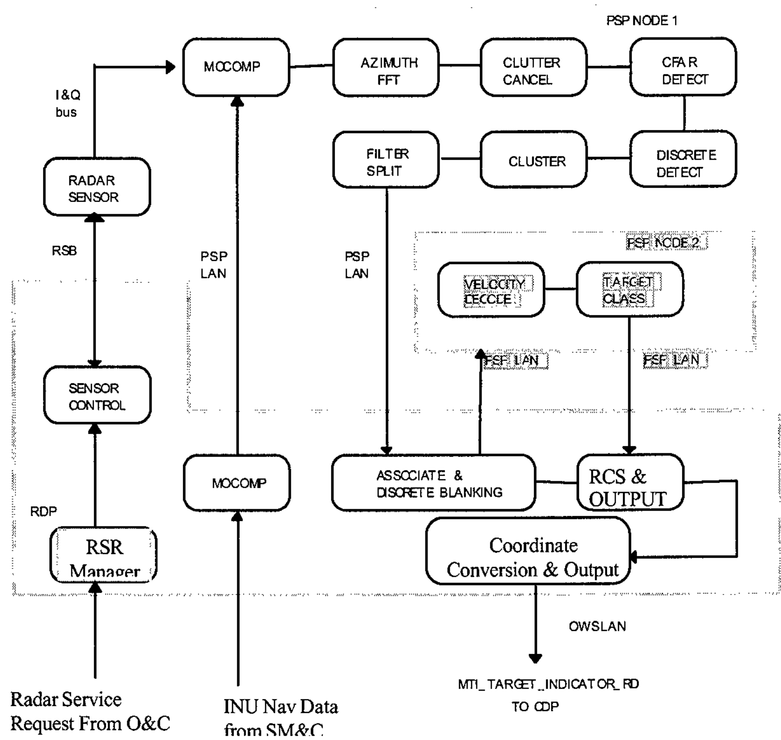

Figure 1-5 RADAR Processing Block Diagram

2 Applicable Documents

The following is a list of the applicable documents:

Document Name	Date of Issue	Revision
Engineering Services Task (EST) Statement of Work E-8C RADAR Processor Simulation System Specification For Joint Surveillance Target Attack RADAR System AN/USY-TBD (JOINT STARS)	21 December 1992	
(U) Prime Item Development Specification For RADAR Subsystem AN/APY-(TBD) For Joint Surveillance Target Attack RADAR System (JOINT STARS)	12 June 1991	

3 Trade Study Candidate Definitions

3.1 Candidate Descriptions

The description of each candidate included in the study is provided in the following paragraphs. These descriptions are conceptual in nature and are not to be considered design requirement definitions.

3.1.1 Candidate One Description

This candidate was conceived on the basic premise of minimizing message traffic flow across hardware buses and to contain the simulation in the same processing unit as the existing MTI processing.

3.1.1.1 Candidate One Block Diagram

The functional block diagram for candidate number one is shown in Figure 3-1 the added functionality is shown as shaded. This candidate requires that all new functionality be placed in the present RADAR Data Processor (RDP) and therefore must meet the present RDP memory and CPU loading requirements.

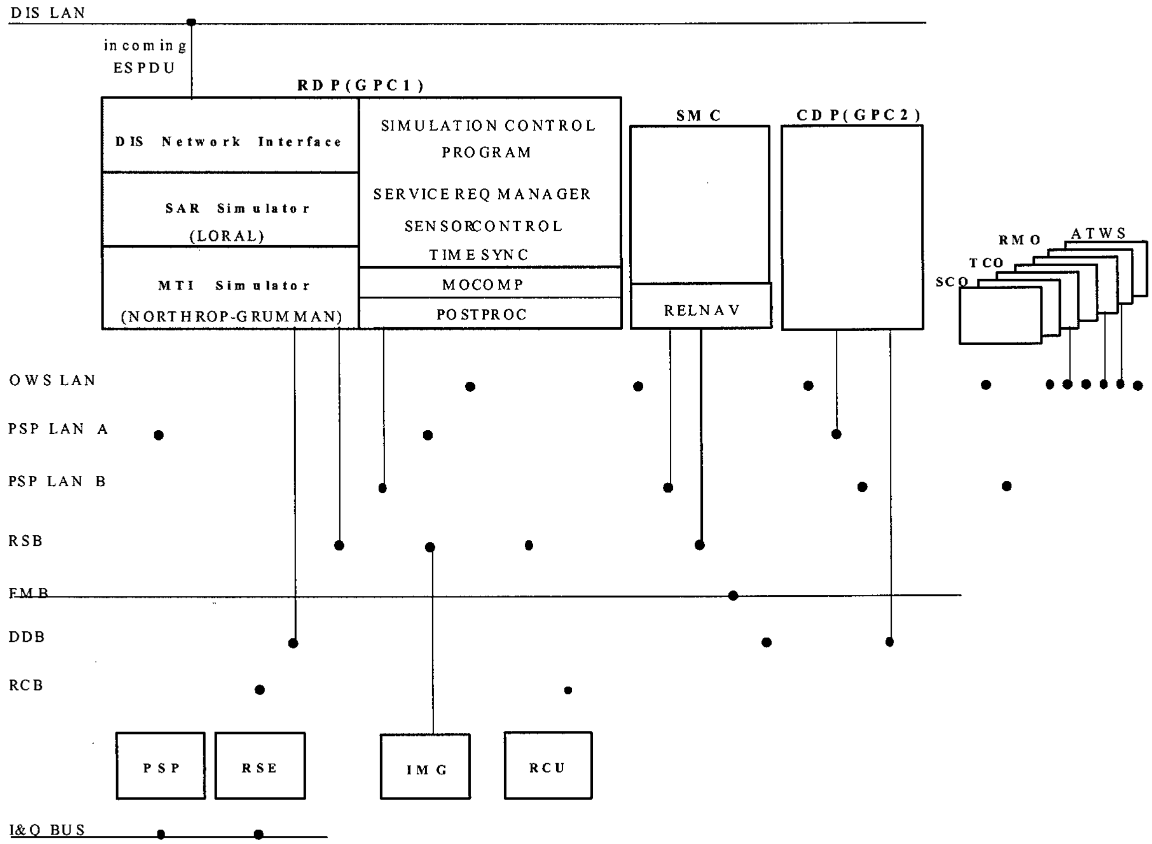

Figure 3-1 Functional Block Diagram Candidate One

3.1.1.2 Candidate One Interface Requirements

This candidate will interface with the DIS network through the PDU interface module which will reside in the RDP. This will be done completely by software and requires no additional hardware interface. The RPS will interface with the existing RADAR sensor control (RSC) and signal processing (POSTPROC) functions via global common areas in the RDP memory and thus does not require any hardware interface bus traffic.

3.1.1.2.1 DIS Network Interface Processing

The candidate processor will receive the entity state information from the DIS and perform the necessary coordinate transformations. This information will be provided to the SAR simulator and the MTI simulator as required, via the Target data base process.

3.1.1.2.2 RPS Control Interface Requirements

The candidate one control processing will perform the overall function of controlling the PDU, SAR simulator and the MTI simulator and as such will be required to interface on a message level with the existing RDP functions. The RPS control program will contain the capability to receive and process the following messages: PSP Parameter messages, and the MTI report message. The RADAR processing functional allocation to the hardware components is shown in Figure 3-2 with the RPS virtual target injection points shown as shaded.

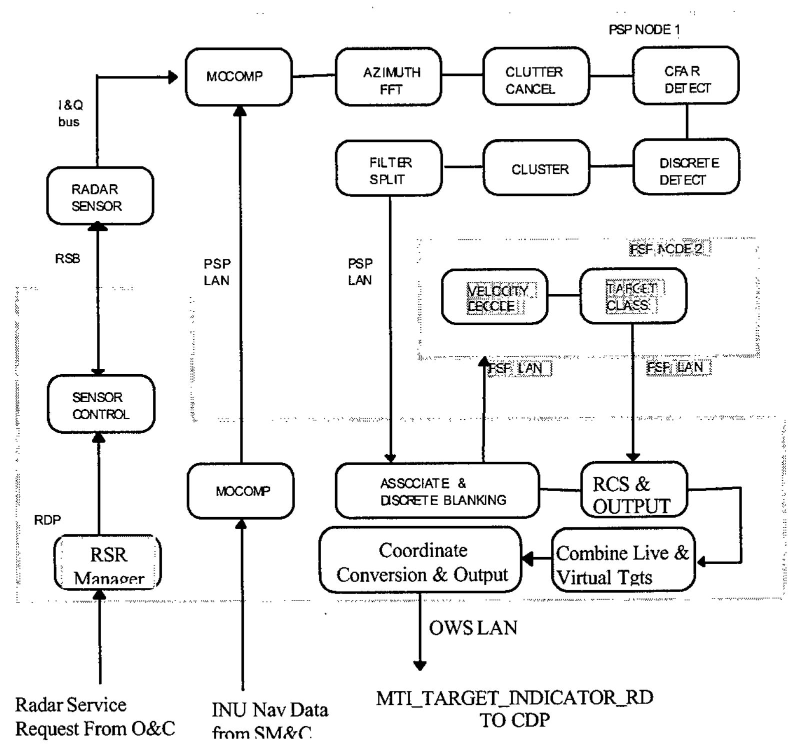

Figure 3-2 RADAR Processing Block Diagram

3.1.1.2.3 SAR Simulator Interface Requirements

The SAR simulator must receive navigation, target, terrain and cultural features data from the RPS control processor. This data will contain the aircraft platform position as a function of time as well as target types, vegetation type, cultural features (such as buildings) and terrain elevation. (The terrain data will be obtained from a disk file containing the predefined exercise database.)

3.1.1.2.4 MTI Simulator Interface Requirements

The MTI simulator will receive moving target information from the RPS control processor. This information will contain target type, target position in TCS coordinates and target velocity. The MTI simulator will generate target detection reports which contain target type, target velocity, target range, and target cone angle. These interface requirements are shown in Figure 3-3.

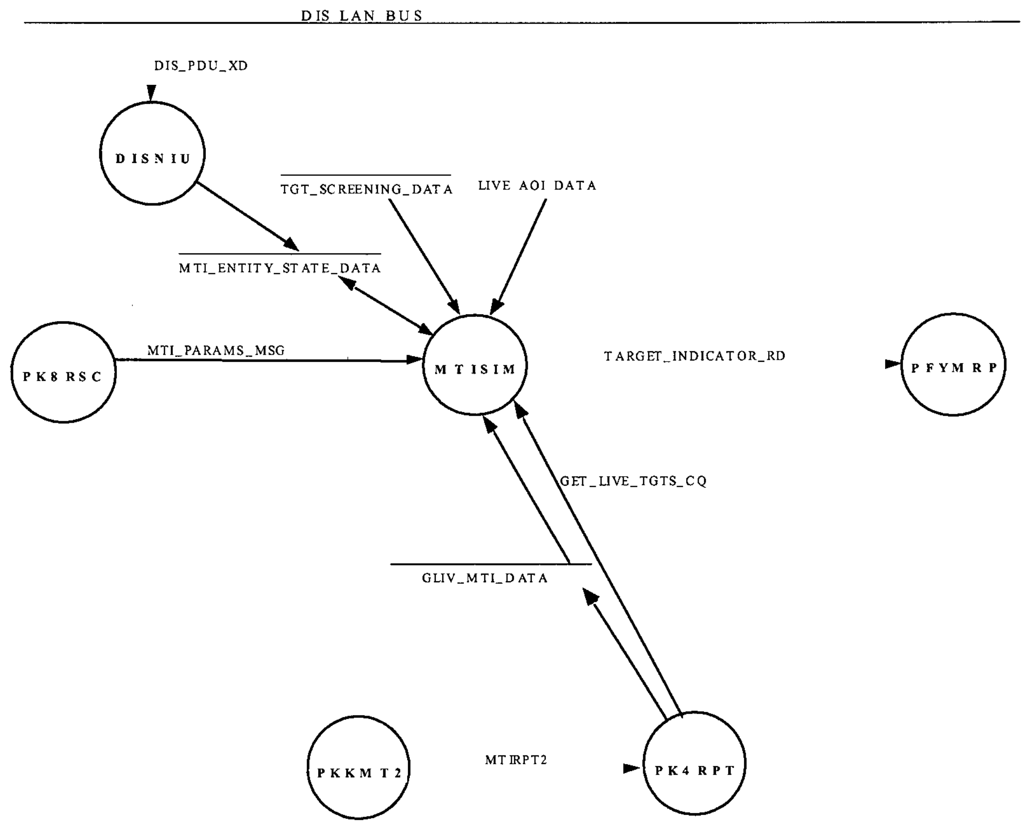

Figure 3-3 MTI Simulator Software Interface Requirements

3.1.1.3 Candidate One Hardware Requirements

This candidate resides in the existing RDP and requires no additional hardware or any modification to the existing hardware.

3.1.1.4 Candidate One Timeline Requirements

This candidate resides in the present RDP which is a Militarized VAX 866 and as such must perform in the existing memory and CPU loading environment. The present design utilizes 3.6 Megabytes of it's existing 64 Megabytes of global common memory and 78.1\% of the CPU is loaded.

3.1.1.4.1 PDU Timeline Requirements

The relative time line requirements, or sequence of events, for the PDU interface unit is shown in Figure3-4 and 3-5.

3.1.1.4.2 SAR Simulator Timeline Requirements

The relative timeline for the present SAR processing is shown in Figure 3-4. The SAR simulator must operate within the bounds of this time line.

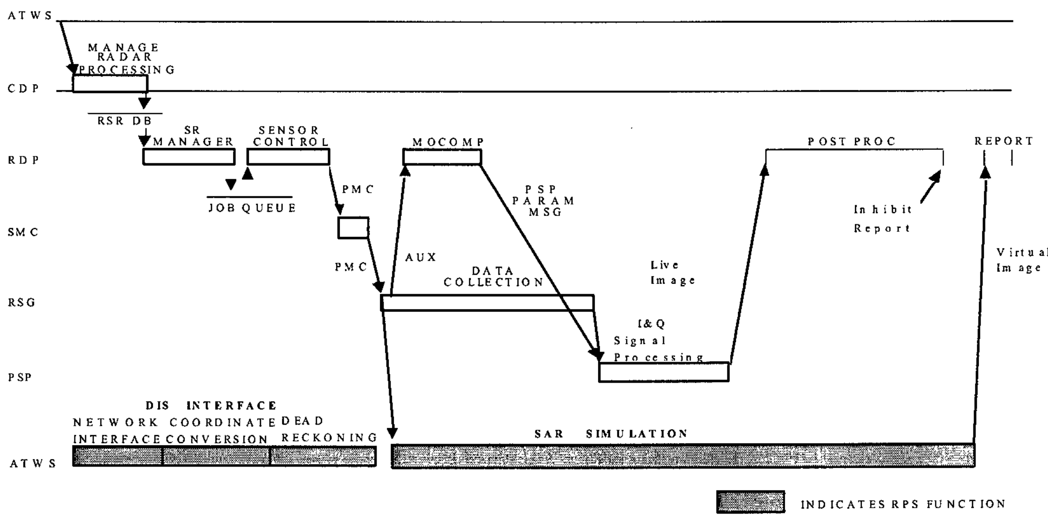

Figure 3-4 SAR Timeline

3.1.1.4.3 MTI Simulator Timeline Requirements

The relative timeline diagram for the MTI simulator for candidate number one is shown in Figure 3-5. The figure shows the relative timeline requirements for each process required to perform the simulation.

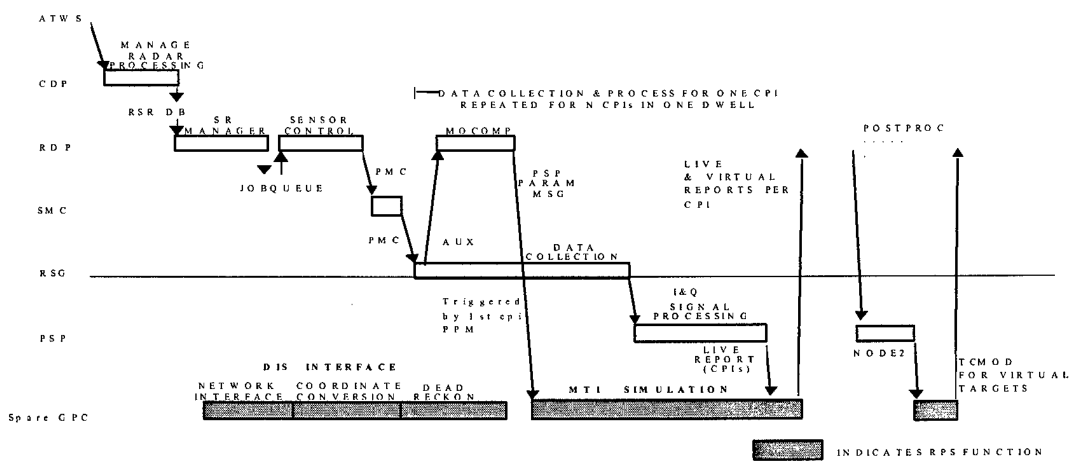

Figure 3-5 MTI Timeline

3.1.1.5 Candidate One Software Requirements

The following software functions must be developed for this candidate ; DIS network interface, RPS control, Dead reckoning processing, SAR simulator, MTI simulator and report processing.

3.1.1.5.1 RPS Control Software Requirements

The RPS control software will be required to perform the simulation initialization, event time line control, simulator control, simulation shut down and error handling.

3.1.1.5.2 PDU Software Requirements

The PDU software will perform all interface functions required to send, receive and decode entity state messages received on the DIS network. The PDU software will also be required to perform all necessary coordinate conversions and target information updating (dead reckoning). The PDU software will be divided into two distinct components, the DIS network interface and the Target data base process. The DIS network interface will be hosted on a Unix based workstation, which will have the necessary software to interface over a LAN to an RF data link. The Target data base process will be hosted in the same processor as the MTI simulator and will also interface with an RF Data link. The processing flow diagram for the PDU process is shown in Figure 3-6.

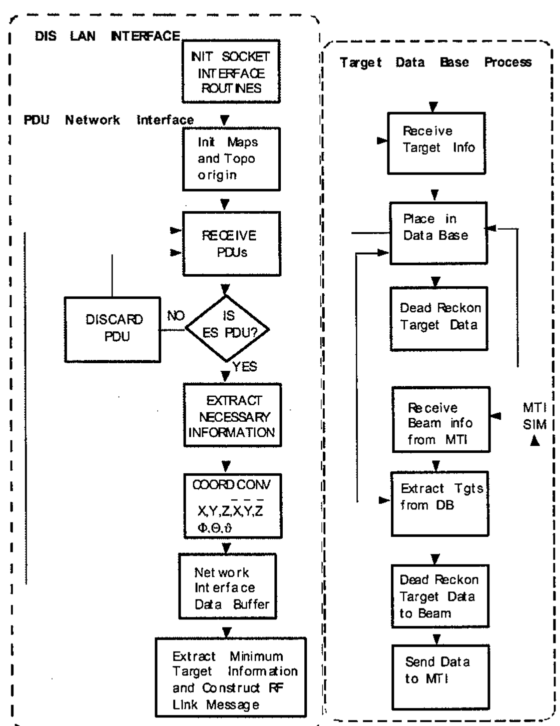

Figure 3-6 Functional Block Diagram PDU Processing

3.1.1.5.3 SAR Simulator Software Requirements

The SAR simulation will receive terrain, target and other entity state information and perform the functions required to generate a proper JOINT STARS SAR image. The SAR simulator will format the image information into the proper JOINT STARS format for transmittal over the Programmable Signal Processor (PSP) LAN to the RDP. The software functional flow for the SAR processing for candidate one is shown in Figure 3-7.

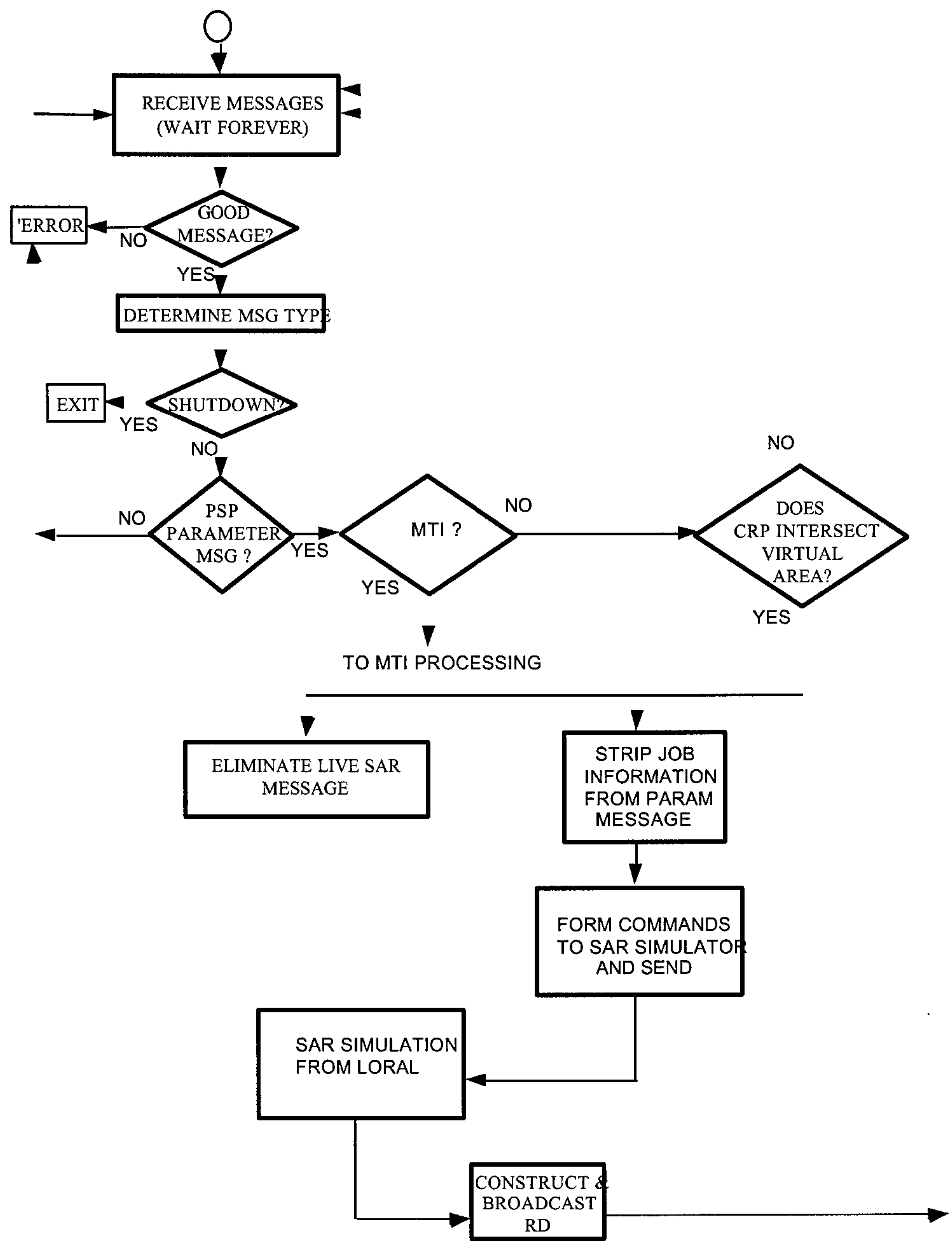

Figure 3-7 SAR Functional Software Flow Diagram Candidate One

3.1.1.5.4 MTI Simulator Software Requirements

The MTI simulator will receive target entity state messages from the RPS control process and perform the necessary functions to emulate the JOINT STARS MTI signal processing. The simulation will be performed on a dwell basis. The software functional flow for the MTI processing for candidate one is shown in Figure 3-8.

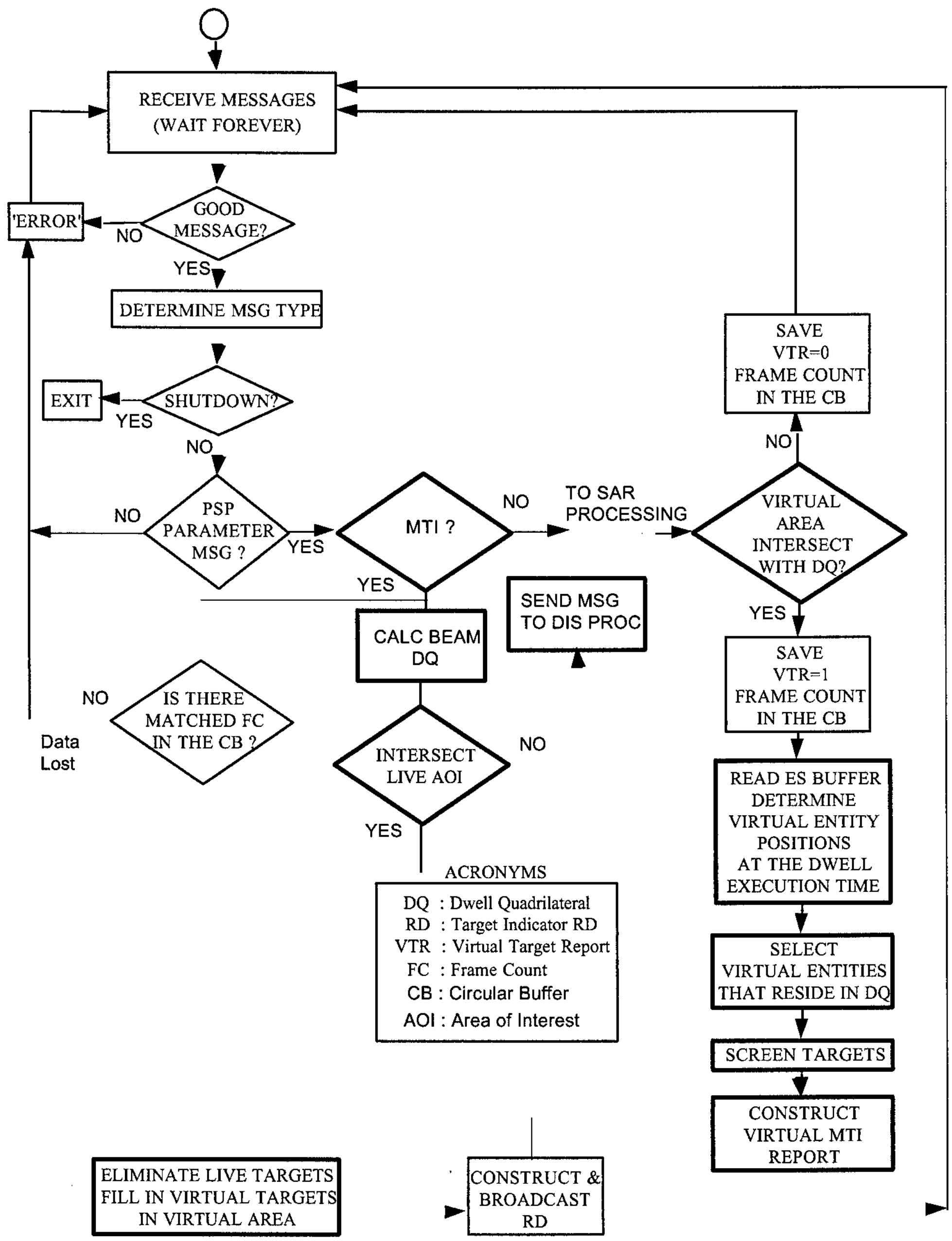

Figure 3-8 Functional Software Flow Diagram Candidate One

3.1.2 Candidate Two Description

This candidate was conceived with the idea of minimizing the impact to the present processing by isolating the new functionality in an independent processor. These would require that the functionality of the spare General Purpose Computer (GPC) be replaced for the exercise period.

3.1.2.1 Candidate Two Block Diagram

The functional block diagram for candidate number two is shown in Figure 3-9 the added functionality is shown as shaded. This candidate requires that the majority of new functionality be placed in the present spare General Purpose Computer. Some control functions will reside in the present RDP as shown in the figure.

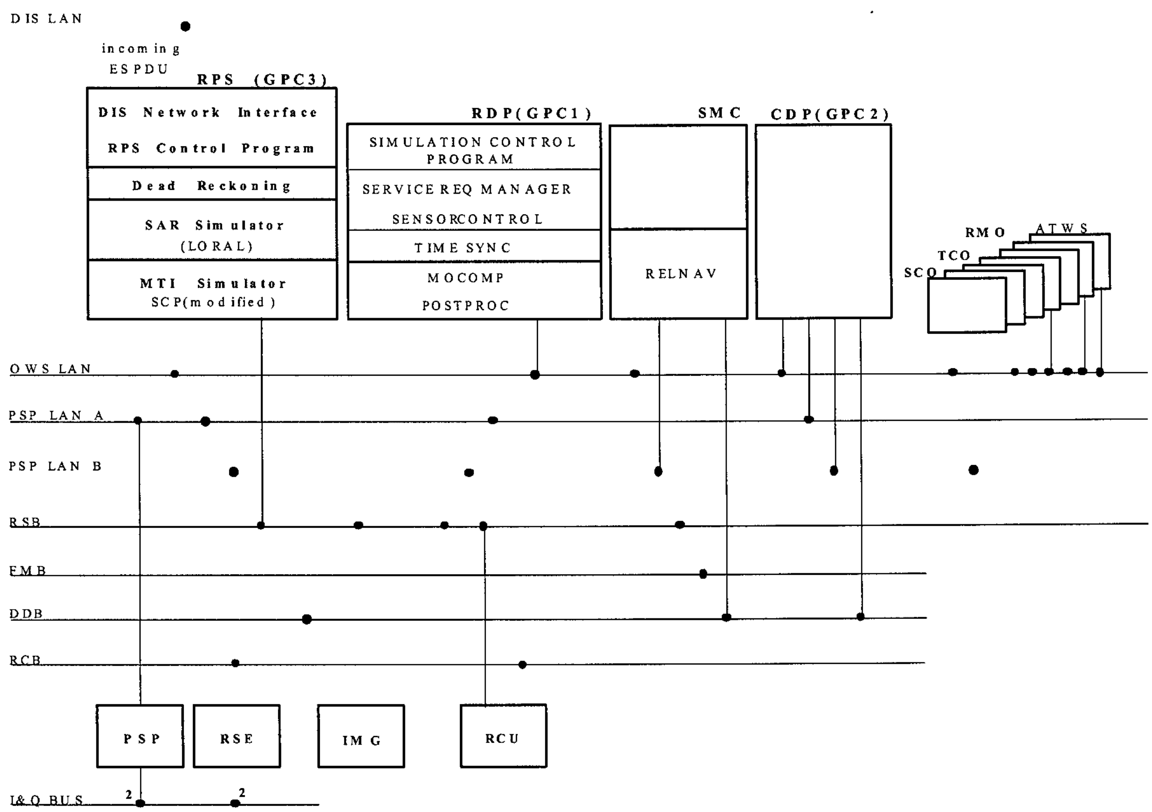

Figure 3-9 Functional Block Diagram Candidate Two

3.1.2.2 Candidate Two Interface Requirements

This candidate will interface with the DIS network through the target data base module which will reside in the Spare GPC. This will be done via a LAN interface. The RPS will interface with the existing RADAR sensor control (RSC) and signal processing (POSTPROC) functions via the PSP and OWS LAN interfaces using message structures which have been developed for communication with the PSPs and CDPs.

3.1.2.2.1 DIS Network Interface Processing

The candidate processor will receive the entity state information from the DIS and perform the necessary coordinate transformations. This information will be provided to the SAR simulator and the MTI simulator as required, via the Target data base process.

3.1.2.2.2 RPS Control Interface Requirements

The candidate two control processing will perform the overall function of controlling the PDU, SAR simulator and the MTI simulator and as such will be required to interface on a message level with the existing RDP functions on the OWS LAN interface. The RPS control program will contain the capability to receive and process the following messages: PSP Parameter messages, and the MTI report message.

3.1.2.2.3 SAR Simulator Interface Requirements

The SAR simulator must receive navigation and target data from the RPS control processor. This data will contain the aircraft platform position as a function of time as well as target types and orientation. The SAR simulator will maintain a data base of hypsographic and cartographic data required to develop the SAR image.

3.1.2.2.4 MTI Simulator Interface Requirements

The MTI simulator will receive moving target information from the RPS control processor. This information will contain target type, target position in TCS coordinates and target velocity. The MTI simulator will generate target detection reports which contain target type, target velocity, target range, and target cone angle.

3.1.2.3 Candidate Two Hardware Requirements

This candidate resides in the existing spare GPC and requires no additional hardware but will cause the spare GPC to be reconfigured to the RPS.

3.1.2.4 Candidate Two Timeline Requirements

3.1.2.4.1 PDU Timeline Requirements

The relative time line requirements, or sequence of events, for the PDU interface unit is shown in Figure 3-10 and Figure 3-11.

3.1.2.4.2 SAR Simulator Timeline Requirements

The relative timeline for the present SAR processing is shown in Figure 3-10. The SAR simulator must operate within the bounds of this time line.

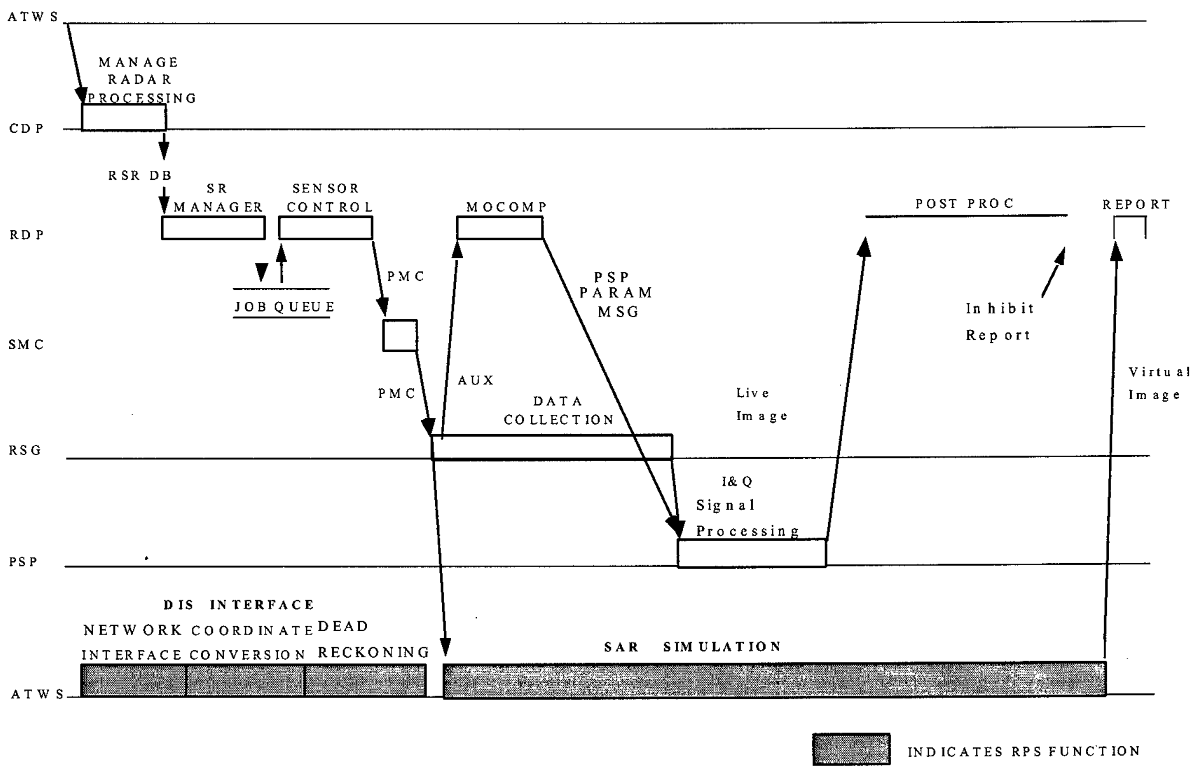

Figure 3-10 SAR Timeline Candidate Two

3.1.2.4.3 MTI Simulator Timeline Requirements

The relative timeline diagram for the MTI simulator for candidate number two is shown in Figure 3-11. The figure shows the relative timeline requirements for each process required to perform the simulation.

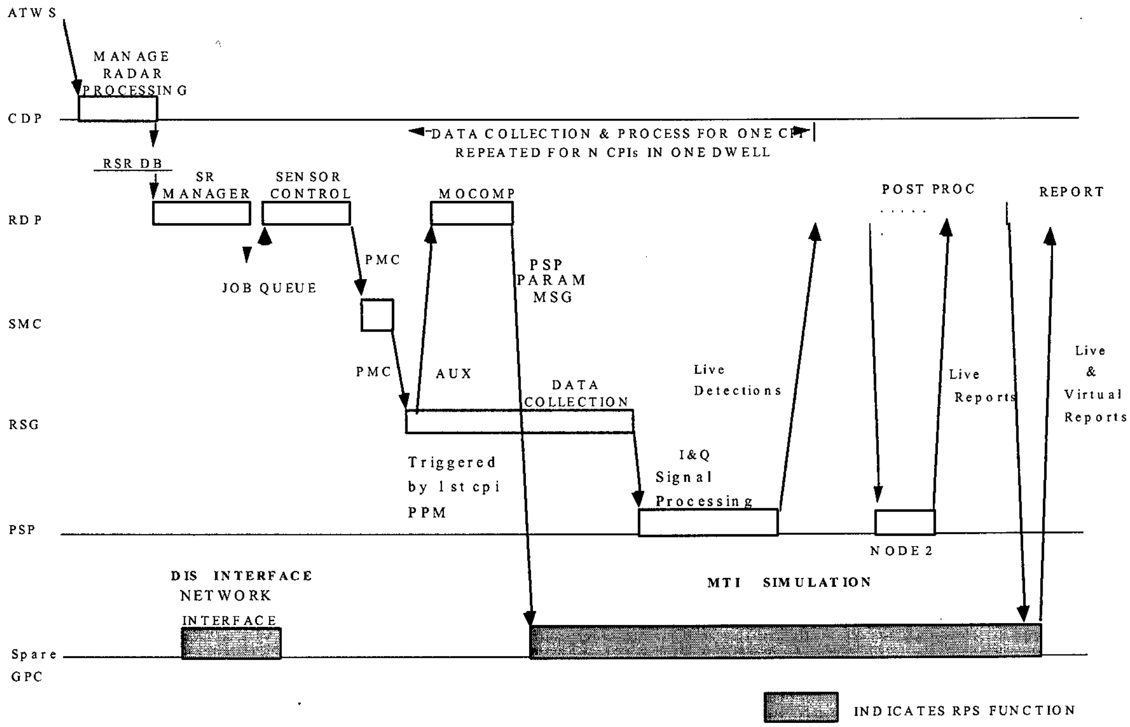

Figure 3-11 MTI Timeline Candidate Two

3.1.2.5 Candidate Two Software Requirements

The following software functions must be developed for this candidate; DIS network interface, RPS control, Dead reckoning processing, SAR simulator, MTI simulator and report processing.

3.1.2.5.1 RPS Control Software Requirements

The RPS control software will be required to perform the simulation initialization, event time line control, simulator control, simulation shut down and error handling.

3.1.2.5.2 PDU Software Requirements

The PDU software will perform all interface functions required to send, receive and decode entity state messages received on the DIS network. The PDU software will also be required to perform all necessary coordinate conversions and target information updating (dead reckoning). The PDU software will be divided into two distinct components, the DIS network interface and the Target data base process. The DIS network interface will be hosted on a Unix based workstation, which will have the necessary software to interface over a LAN to an RF data link. The Target data base process will be hosted in the same processor as the MTI simulator and will also interface with an RF Data link. The processing flow diagram for the PDU process is shown in Figure 3-6.

3.1.2.5.3 SAR Simulator Software Requirements

The SAR simulation will receive terrain, target and other entity state information and perform the functions required to generate a proper JOINT STARS SAR image. The SAR simulator will format the image information into the proper JOINT STARS format for transmittal over the Programmable Signal Processor (PSP) LAN to the RDP. The software functional flow for the SAR processing for candidate two is shown in Figure 3-7.

3.1.2.5.4 MTI Simulator Software Requirements

The MTI simulator will receive virtual target data from the RPS control process and perform the necessary functions to emulate the JOINT STARS MTI signal processing. The simulation will be performed on a dwell basis. The software functional flow for the MTI processing for candidate two is shown in Figure 3-12.

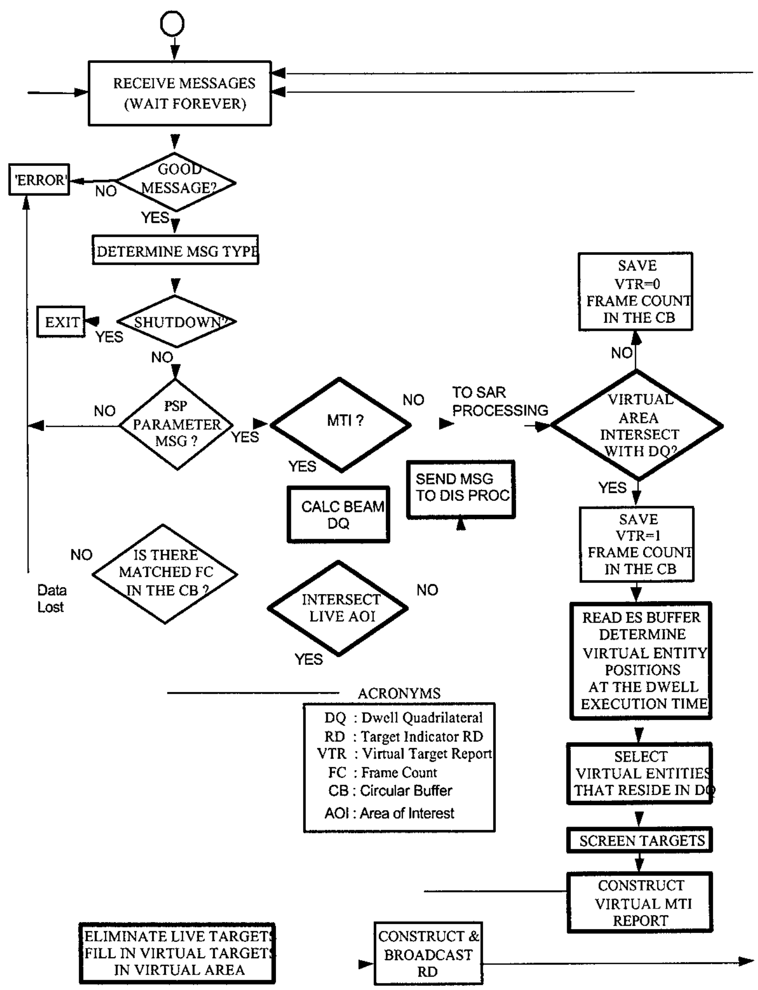

Figure 3-12 Functional Software Flow Diagram Candidate Two

3.1.3 Candidate Three Description

This candidate was conceived with the idea of increasing the fidelity of the simulation or lowering the level at which the simulation will be performed. This candidate will develop RADAR models and simulations at the Coherent Processing Interval (CPI) level. Implementation of this candidate will require modeling the PSP detection process. The functionality of the spare General Purpose Computer (GPC) be replaced by the RPS.

3.1.3.1 Candidate Three Block Diagram

The functional block diagram for candidate number three is shown in Figure 3-13 the added functionality is shown as shaded. This candidate requires that all of the new functionality be placed in the present spare GPC. The processing required in candidate number three will be performed at the coherent processing interval (CPI) level. This will require that the RPS capture the PSP Node1 message and inject the virtual targets every CPI. This will have some impact on the RADAR timeline.

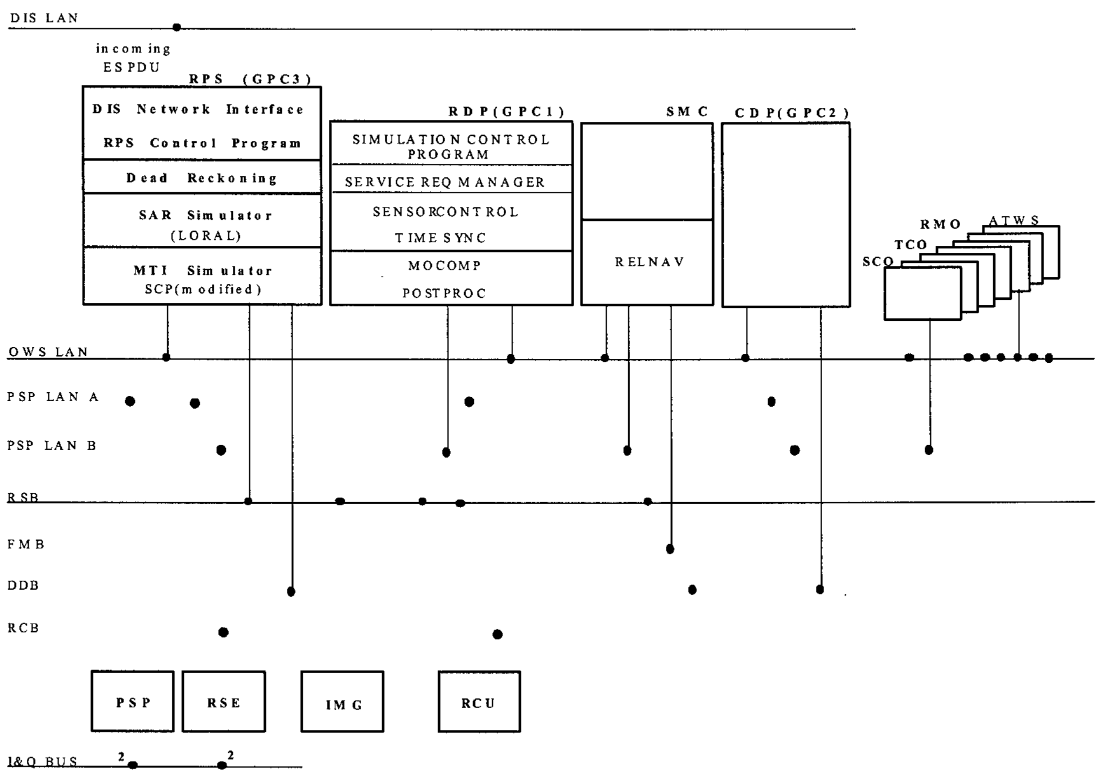

Figure 3-13 Functional Block Diagram Candidate Three

3.1.3.2 Candidate Three Interface Requirements

This candidate will interface with the DIS network through the PDU interface module which will reside in the Spare GPC. This will be done completely by software and requires no additional hardware interface. The RPS will interface with the existing RADAR sensor control (RSC) and signal processing (POSTPROC) functions via the PSP and OWS LAN interfaces using message structures which have been developed for communication with the PSPs and CDPs.

3.1.3.2.1 DIS Network Interface Processing

The candidate processor will receive the entity state information from the DIS and perform the necessary coordinate transformations. This information will be provided to the SAR simulator and the MTI simulator as required, via the Target data base process.

3.1.3.2.2 RPS Control Interface Requirements

The candidate three control processing will perform the overall function of controlling the PDU, SAR simulator and the MTI simulator and as such will be required to interface on the PSP LAN with the existing RDP functions. Portion of the control process will reside in the spare GPC and the RDP. The RPS control program will contain the capability to receive and process the following messages: PSP Setup messages, PSP Parameter messages, the MTI report node 1 message, and the PSP node 2 messages.

3.1.3.2.3 SAR Simulator Interface Requirements

The SAR simulator must receive navigation and target data from the RPS control processor. This data will contain the aircraft platform position as a function of time as well as target types and orientation. The SAR simulator will maintain a data base of hypsographic and cartographic data required to develop the SAR image.

3.1.3.2.4 MTI Simulator Interface Requirements

The MTI simulator will receive moving target information from the RPS control processor. This information will contain target type, target position in TCS coordinates and target velocity. The MTI simulator will generate target locations in range; cone angle and associate these target characteristics with the appropriate CPIs. These targets will be added to the existing node 1 message which is transmitted by the PSP to the RDP via the PSP LAN.

3.1.3.3 Candidate Three Hardware Requirements

This candidate resides in the existing spare GPC and requires no additional hardware but will cause the spare GPC to be reconfigured to the RPS.

3.1.3.4 Candidate Three Timeline Requirements

3.1.3.4.1 PDU Timeline Requirements

The relative time line requirements, or sequence of events, for the PDU interface unit is shown in Figure 3-14 and Figure 3-15.

3.1.3.4.2 SAR Simulator Timeline Requirements

The relative timeline for the present SAR processing is shown in Figure 3-14. The SAR simulator must operate within the bounds of this time line.

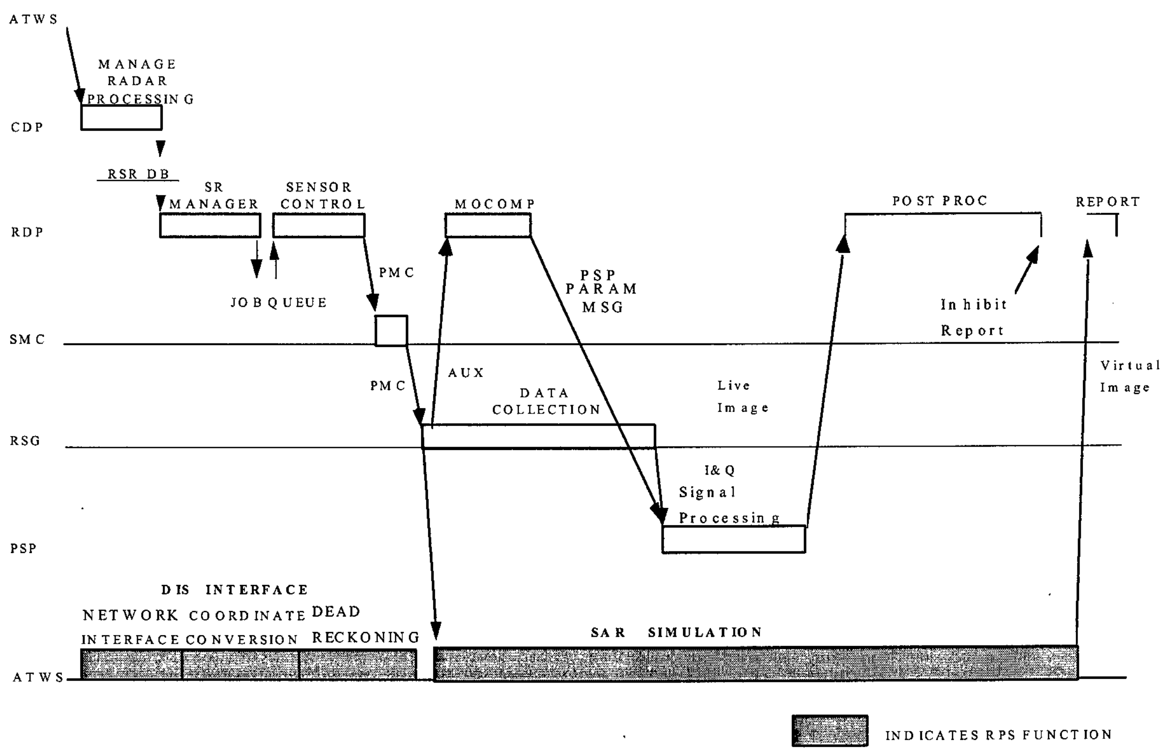

Figure 3-14 SAR Timeline Candidate Three

3.1.3.4.3 MTI Simulator Timeline Requirements

The relative timeline diagram for the MTI simulator for candidate number three is shown in Figure 3-15. The figure shows the relative timeline requirements for each process required to perform the simulation.

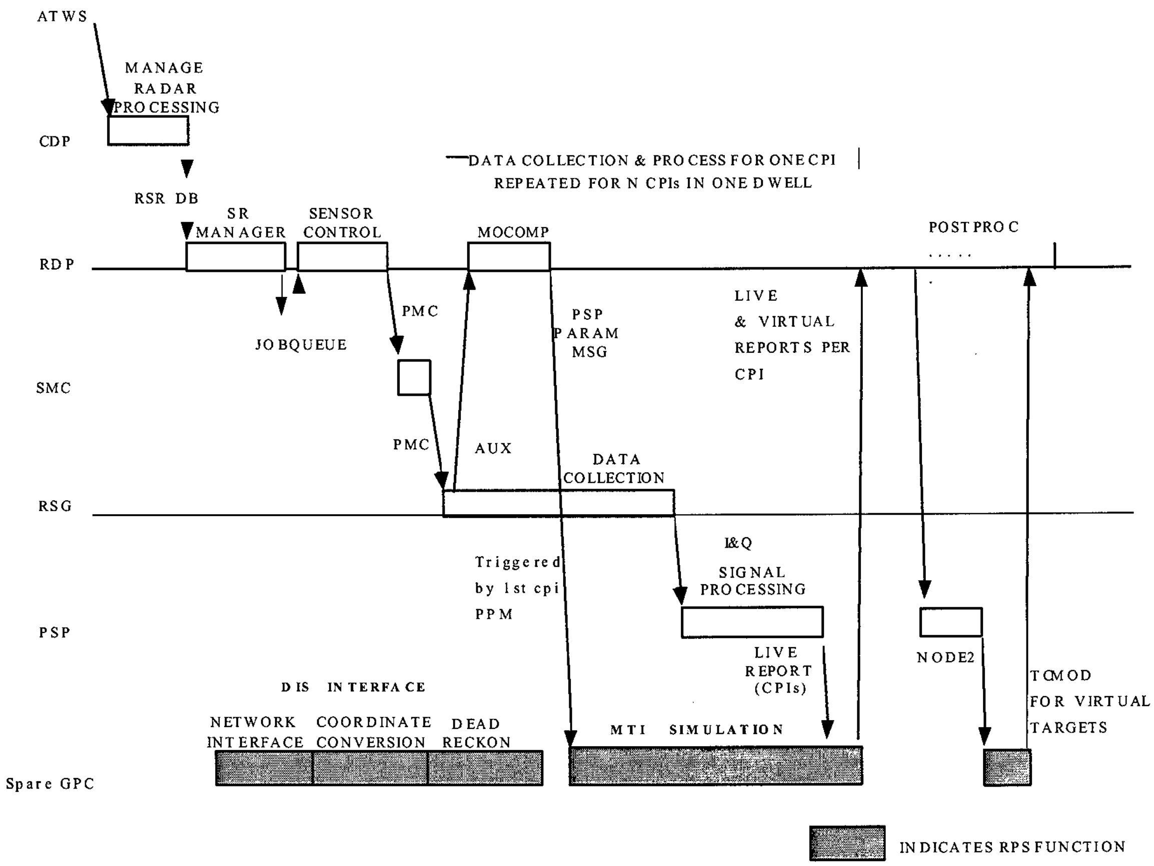

Figure 3-15 MTI Timeline Candidate Three

3.1.3.5 Candidate Three Software Requirements

The following software functions must be developed for this candidate ; DIS network interface, RPS control, Dead reckoning processing, SAR simulator, MTI simulator and node 1 and node 2 report processing.

3.1.3.5.1 RPS Control Software Requirements

The RPS control software will be required to perform the simulation initialization, event time line control, simulator control, simulation shut down and error handling.

3.1.3.5.2 PDU Software Requirements

The PDU software will perform all interface functions required to send, receive and decode entity state messages received on the DIS network. The PDU software will also be required to perform all necessary coordinate conversions and target information updating (dead reckoning). The PDU software will be divided into two distinct components, the DIS network interface and the Target data base process. The DIS network interface will be hosted on a Unix based workstation, which will have the necessary software to interface over a LAN to an RF data link. Target data base The process will be hosted in the same processor as the MTI simulator and will also interface with an RF Data link. The processing flow diagram for the PDU process is shown in Figure 3-6.

3.1.3.5.3 SAR Simulator Software Requirements

The SAR simulation will receive terrain, target and other entity state information and perform the functions required to generate a proper JOINT STARS SAR image. The SAR simulator will format the image information into the proper JOINT STARS format for transmittal over the Programmable Signal Processor (PSP) LAN to the RDP. The software functional flow for the SAR processing for candidate three is shown in Figure 3-7.

3.1.3.5.4 MTI Simulator Software Requirements

The MTI simulator will receive target entity state messages from the RPS control process and perform the necessary functions to emulate the JOINT STARS MTI signal processing. The simulation will be performed on a CPI basis. The software functional flow for the MTI processing for candidate three is shown in Figure 3-16.

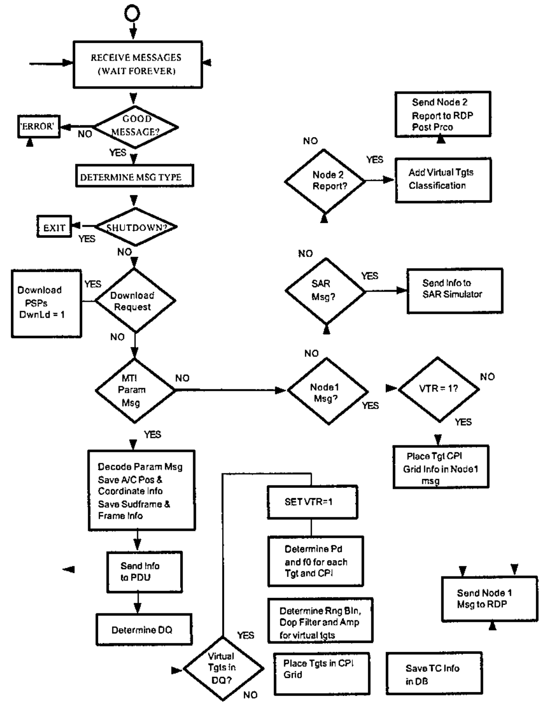

Figure 3-16 Functional Software Flow Diagram Candidate Three

4 Trade Study Process

The following paragraphs comprise the trade study evaluation requirements for the architectural study for the RPS. Architecture candidates were identified and evaluated based on the criteria described in the following paragraphs. The criteria and their associated weights are given in Table 4-1 Evaluation Criteria. Each criterion was assigned a pre-weighted value from 1 to 3 based on the candidates impact on the specific criteria.

Criterion	Weight
Timeline Impact	10
Memory Requirements	2
System Loading	8
Modification of Existing Software	9
Modification or Addition of Hardware	6
Use of Existing Simulations and Models	4
Level of Simulation	4
Integration Complexity	5
Expandability/Growth	6

Table 4-1 Evaluation Criteria

4.1 Candidate Evaluation Criteria

The conceptual architectural designs were evaluated on the criteria delineated in the following paragraphs. Each criterion was assigned a weighting factor to be used in the evaluation process.

4.1.1 JOINT-STARS Timeline Impact

Each candidate was evaluated based on its impact to the present JOINT-STARS timeline. Those candidates which have the smallest impact on the timeline were given the higher scores. Timeline impacts to the RADAR subsystem are more heavily weighted than impacts to the O\&C subsystem. The RADAR timeline has more effect on total system performance.

4.1.2 Memory Requirements

Each candidate was evaluated based on the amount of memory required to implement the design. Those candidates with lower memory requirements received higher ratings.

4.1.3 JOINT-STARS System Loading

Each candidate was evaluated based on its effect on maximum system loading capabilities. Those candidates with least effect were given higher ratings.

4.1.4 Modification of Existing Software

Each candidate was evaluated based on the amount of changes to existing software. The goal was to minimize changes to the present JSTARS software in order to reduce regression testing liability. However, minor changes are acceptable and expected. Candidates requiring the least amount of changes to existing software achieved the highest ratings.

4.1.5 Modification or Addition of Hardware

Each candidate was evaluated based on the amount of modifications required to existing hardware or the addition of hardware. It was desired not to make any hardware changes therefore, candidates requiring hardware changes/additions received low ratings.

4.1.6 Use of Existing Simulations and Models

Each candidate was evaluated based on the number of simulations and models to be developed versus use of existing code. The candidates which require the least new code development received the highest ratings.

4.1.7 Level of Simulation

Each candidate was evaluated based on the level of the simulations used. It was desired to keep the simulations and models at the highest level possible (e.g. simulated at the target report level). Those candidates which require lower level simulations and models are given lower ratings because in general they will have increased complexity.

4.1.8 Integration Requirements

Each candidate was evaluated based on its integration requirements, that is to say, the amount of hardware, software and facilities required for integration purposes. The candidates which require the most hardware, software and facilities obtained lower ratings.

4.1.9 Expandability/Growth Capabilities

Each candidate was evaluated based on its capability of being expanded at a later date. These candidates will incorporate more general design concepts that inherently lead to their expandability. These candidates will receive higher ratings than those which restrict or inhibit future growth.

4.2 Prototype Software Development

The trade study was performed on the candidates delineated in the previous paragraphs of this report. In most cases the information used to conduct the trade study was available from the conceptual design process of the candidate. However, in some limited cases the information was not obtainable from the conceptual design, in these cases some level of prototype software code development was necessary. Prototype code is defined as code which performs the desired functionality but which has not been optimized for performance. As an example prototype code will in some cases utilize stubs. Stubs are subroutine calls which return immediately to the calling process without performing any calculations or function. This allows the testing of message flow and handling without performing the detail design function.

4.3 Hardware

In most cases the Prime Mission Equipment (PME) was not available for performing in depth timing studies. Therefore, an alternate hardware host was used for timing comparisons. A VAX 4000 series 90 was used as the host. Increased performance may be expected when the code is hosted on the targeted PME processors. The timing data presented in this report must be viewed as a relative measure of performance and should not be used to predict absolute performance. The hardware set up for the timing data collection is shown in Figure 4-2 and Figure 4-3.

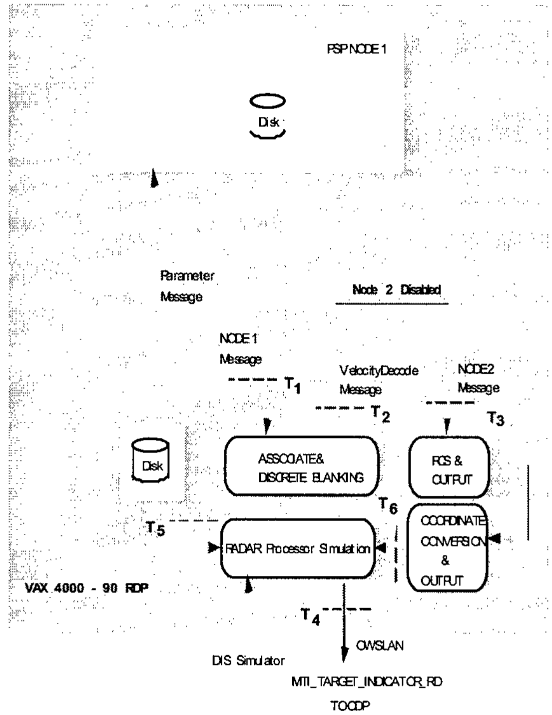

Figure 4-1 Timing Data Collection Setup Candidate number 1

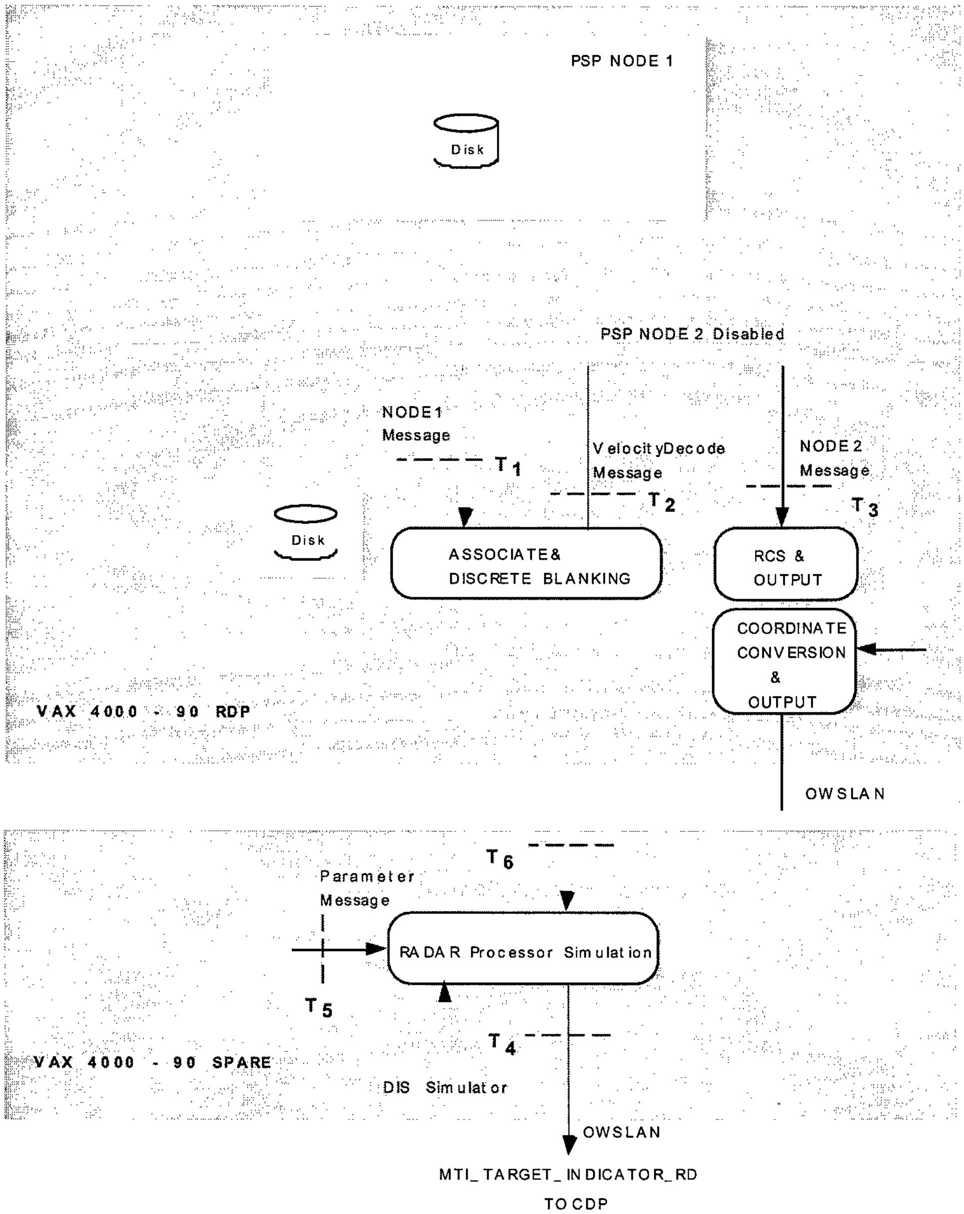

Figure 4-2 Timing Data Collection Setup Candidate number 2

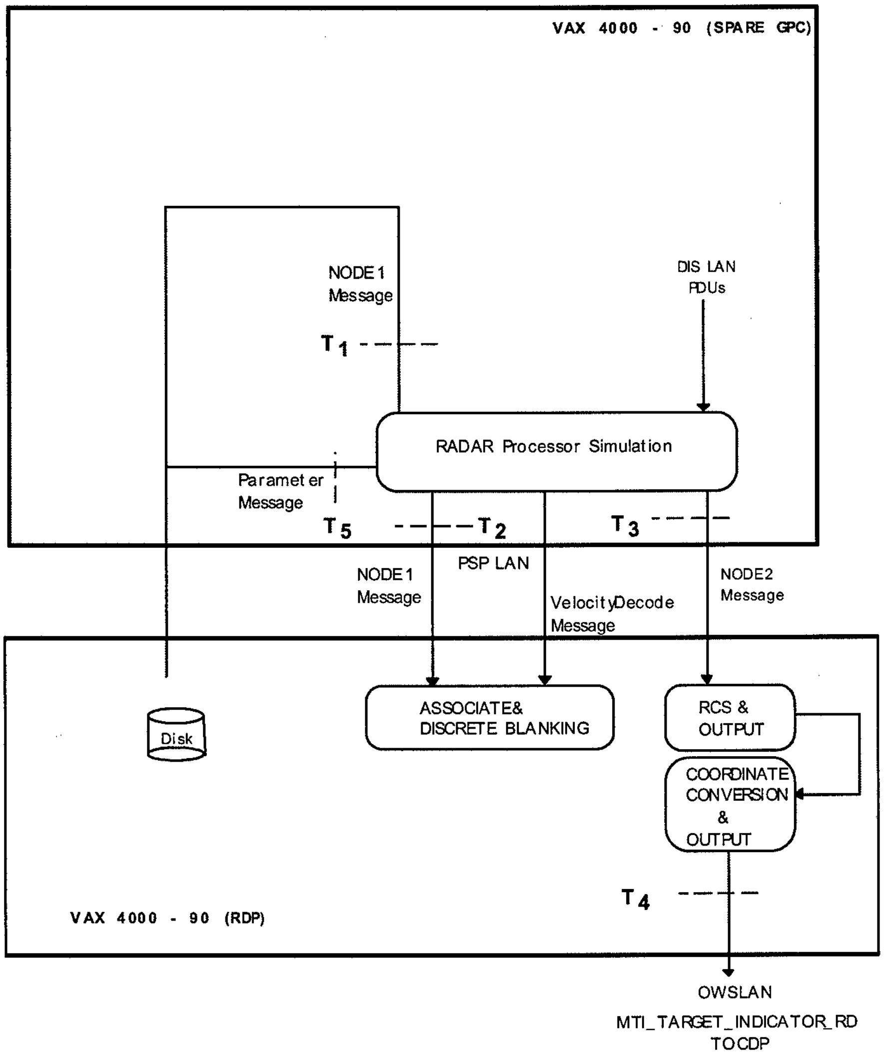

Figure 4-3 Timing Data Collection Setup Candidate number 3

4.4 Test Scenario

In order to compare timeline impacts, memory utilization and other trade study criteria it was necessary to develop a standard test scenario. This scenario consists of a virtual target area (24 km x 24 km) and a live target area (4 km x 4 km). The virtual area will typically be larger than the live target area. The area of interest (AOI) is the search area (10 km x 10 km) as requested by the operator and is where the combination of live and virtual targets will be reported. A diagram of the scenario is shown in Figure 4-4. The live area contains 60 targets (as shown in Figure 4-5) and the virtual area contains 5000 targets as shown in Figure 4-6). All trade study tests use this scenario for determining performance.

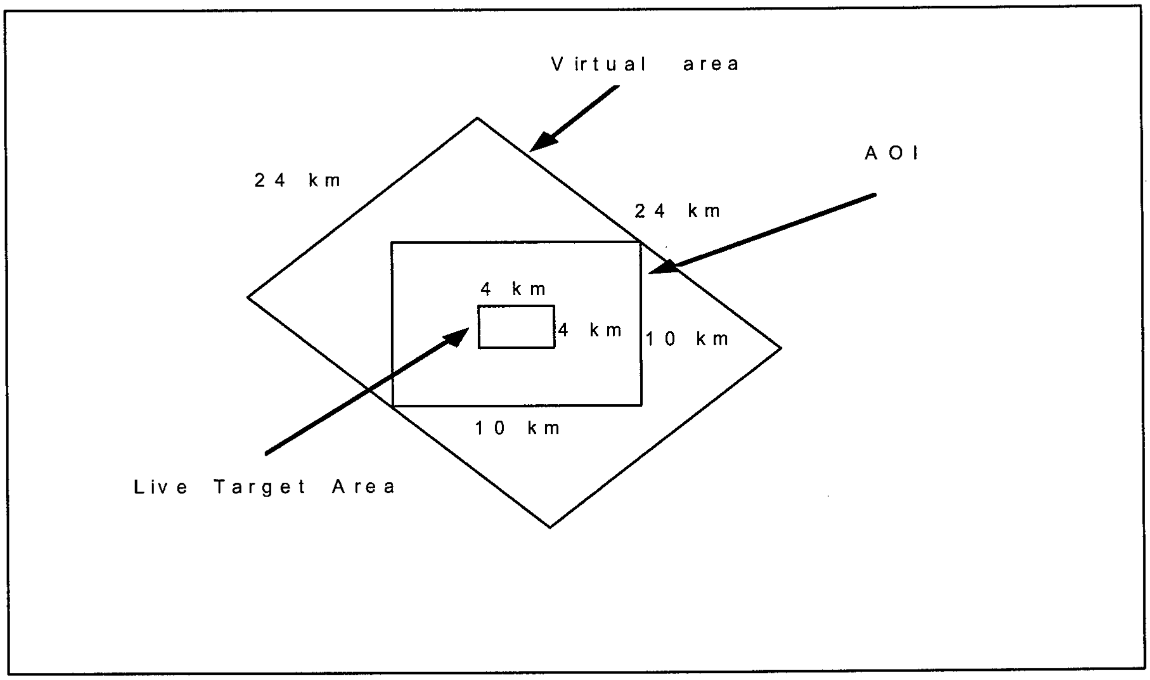

Figure 4-4 Test Scenario Layout

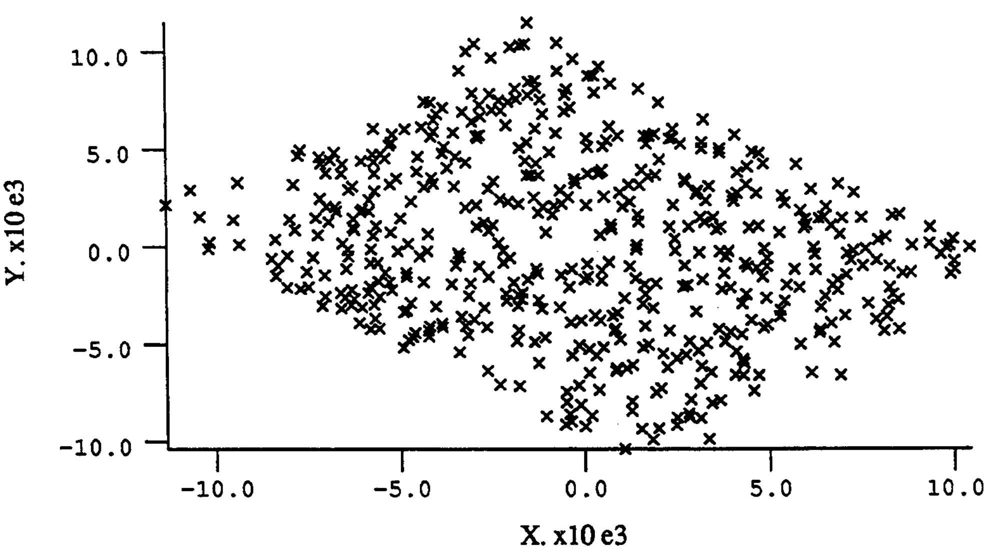

Figure 4-5 Test Scenario Live Target Layout

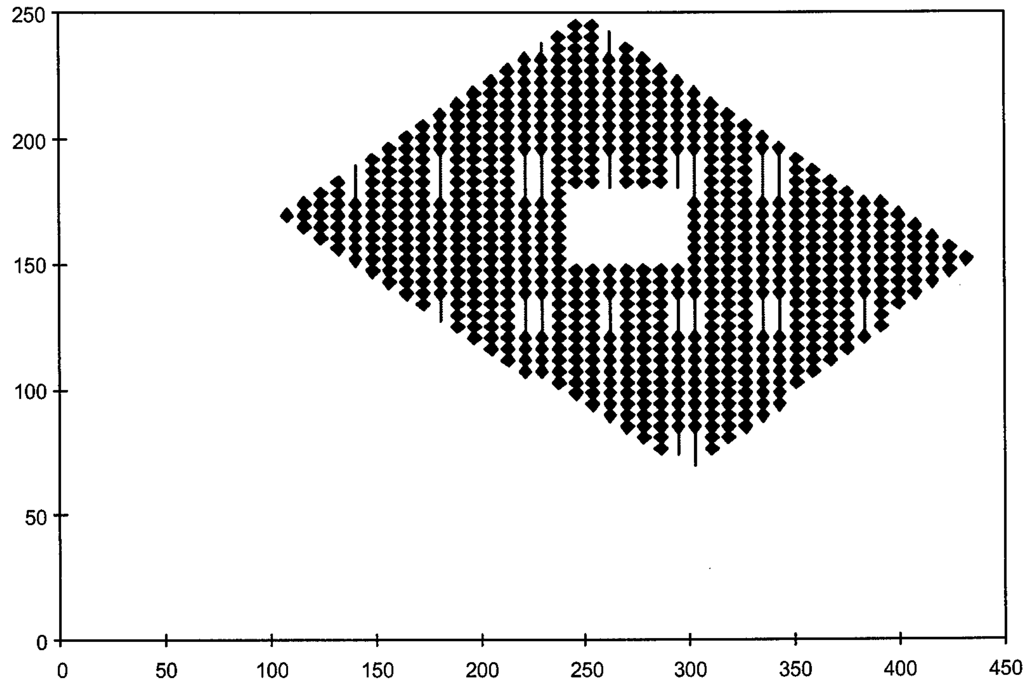

Figure 4-6 Test Scenario Virtual Target Layout

5 Trade Study Results

This section will present the results of the trade study for each candidate. The criteria is shown in Table 4-1 Evaluation Criteria. The performance of each candidate was evaluated for each of the criterion listed and the results are presented in this section of the report.

5.1 Standard Scenario Baseline Results

5.1.1 Timeline Impact Candidate One

The timing results presented here will be of a relative nature only since the actual RADAR timeline is a very complex non-linear function of target loading. The baseline RDP timeline is shown in Table 5-1.

Measurement POINT	Average Number of Dwells	Average Time (msec) Per Dwell
$T_2 - T_1$	158	1,739
$T_4 - T_3$	158	30

Table 5-1 MTI Baseline Timing

5.1.2 Standard Scenario Baseline Memory Requirements

The memory requirements presented here will be of a relative nature only since the actual RADAR memory utilization is target dependent. The baseline RDP memory utilization is 3.6 megabytes.

5.1.3 Standard Scenario Baseline System Loading

The CPU utilization for the standard target scenario is shown in Figure 5-1. The CPU utilization for the MTI processes,PK4MTI and PK4RPT are very low since the target load is low. The process PKXAUX which reads the sensor auxiliary data from a recorded file actually takes more CPU time than the MTI processing.

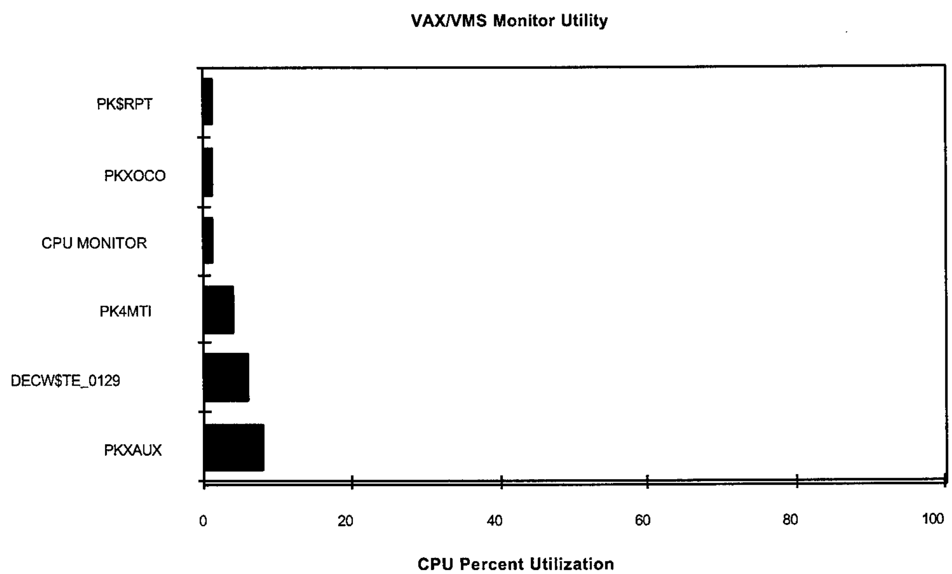

Figure 5-1 Standard Scenario Baseline CPU Utilization

5.2 Trade Study Results Candidate One

The following paragraphs describe the performance expected for candidate number one.

5.2.1 Timeline Impact Candidate One

The timing data was collected with a set dead reckoning update rate of 10 hz. This was done to investigate the effect of worst case dead reckoning on the overall timeline. The estimated timing for candidate number one is summarized in Table ~\ref{time_one_10hz}.

\input{sw_time_c1_10hz.tex}

5.2.2 Memory Requirements Candidate One

The estimated additional memory utilized for candidate number one over the baseline 3.6 megabytes is summarized in Table 5-2.

Process Name	5,000 DIS TGTS	10,000 DIS TGTS	20,000 DIS TGTS
MTIRPT	1.2 Mbyte	2.4 Mbyte	4.8 Mbyte
MTISIM	3.6 Mbyte	7.2 Mbyte	14.4 Mbyte
DISNIU	2.4 Mbyte	4.8 Mbyte	9.6 Mbyte
DISNIU (DR)	n/a	n/a	n/a
PK4MTI	n/a	n/a	n/a
PK4RPT	n/a	n/a	n/a

Table 5-2 Estimated Memory Utilization Candidate Number One

5.2.3 System Loading Candidate One

A typical CPU utilization plot for candidate number one is shown in Figure 5-2. The JADS DIS process takes most of the available CPU with an average CPU utilization of 60\% for this case.

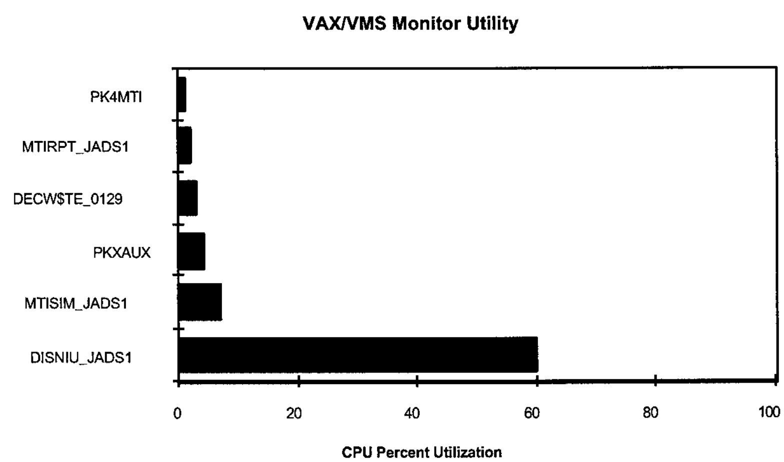

Figure 5-2 Standard Scenario Candidate 1 CPU Utilization

5.2.4 Modification of Existing Software Candidate One

The new software modules which will be required to be developed for candidate number one are shown in Tables ~\ref{sw_new_rpt_one}, \ref{sw_new_sim_one} and \ref{sw_new_dis_one}.

\input{new_code_c1_rpt_table.tex}

\input{new_code_c1_sim_table.tex}
\input{new_code_c1_dis_table.tex}

The estimated modified lines of code for candidate number one is summarized in Table 5-3.

PK4RPT Process		
Software Module	Function	Lines of Code
SKRP01_MTI_REPORT	Main program unit for this process.	3
SKRP02_INIT_REPORT	Initializes the PK4RPT process to JSTARS s/w. Added mapping to the GLIV_MTI_DATA global section.	2
SKRP05_RETRIEVE_DATA	Receives incoming messages. Modified to receive the RPT_TEST_ PARAMS_CQ message from the MTIRPT process.	8
SKRP0B_DATA_TO_OCO	Sends the final MTI report onto the MTI DATA MOT queue. Modified to put the Live MTI data into the GLIV_MTI_DATA global section instead of the MTI DATA MOT queue, and subsequently notify MTIRPT that the Live MTI data is ready	17
PK4RPT Totals:		29

Table 5-3 Estimated Modified Lines of Code Candidate Number One

5.2.5 Modification or Addition of Hardware Candidate One

Candidate number one does not require the modification or addition of any hardware components to the JSTARS system.

5.2.6 Use of Existing Simulations and Models Candidate One

Candidate number one uses the screening code and coordinate conversion code which was developed during the Joint STARS FSD program.

5.2.7 Level of Simulation Candidate One

The RPS candidate number one is implemented at the RADAR report level. This means that all the MTI target detection, target classification, and location accuracy processing are simulated by the RPS.

5.2.8 Integration Complexity Candidate One

The integration complexity of candidate one is high because the RPS is not well partitioned from the JOINT STARS prime mission equipment (PME) software. The ideal integration situation is to be able to monitor data flow between processes on an external interface. This will not be possible with candidate number one since it resides in the same processor as the PME software. Therefore intrusive software techniques must be used, such as debuggers, to determine faults.

5.2.9 Expandability/Growth Candidate One

The expandability of RPS candidate number one is limited by the fact that candidate number one is running in the same processors as the PME software and will start to effect the timeline under the full target loading. The exact point at which the live targets are effected were not determined during this study. However, some indication of the effect can be seen in the time data versus virtual target load presented in Table ~\ref{time_one_10hz}.

5.3 Trade Study Results Candidate Two

The following paragraphs describe the performance expected for candidate number two.

5.3.1 Timeline Impact Candidate Two

The timing results presented here will be of a relative nature only since the actual RADAR timeline is a very complex non-linear function of target loading. The estimated timing for candidate number two is summarized in Table ~\ref{time_two_10hz}.

\input{sw_time_c2_10hz.tex}

5.3.2 Memory Requirements Candidate Two

The memory requirements presented here will be of a relative nature only since the actual RADAR memory utilization is target dependent. The baseline SPARE GPC memory utilization is zero during normal RADAR operation. The estimated SPARE GPC memory utilization for candidate number two is summarized in Table ~\ref{memory_two}.

\input{sw_memory_c2.tex}

5.3.3 System Loading Candidate Two

A typical CPU utilization plot for candidate number two is shown in Figure 5-3 for the RDP processes and Figure 5-4 for the Spare GPC processes. The JADS DIS process takes most of the available CPU with an average GPC CPU utilization of 75\% for this case.

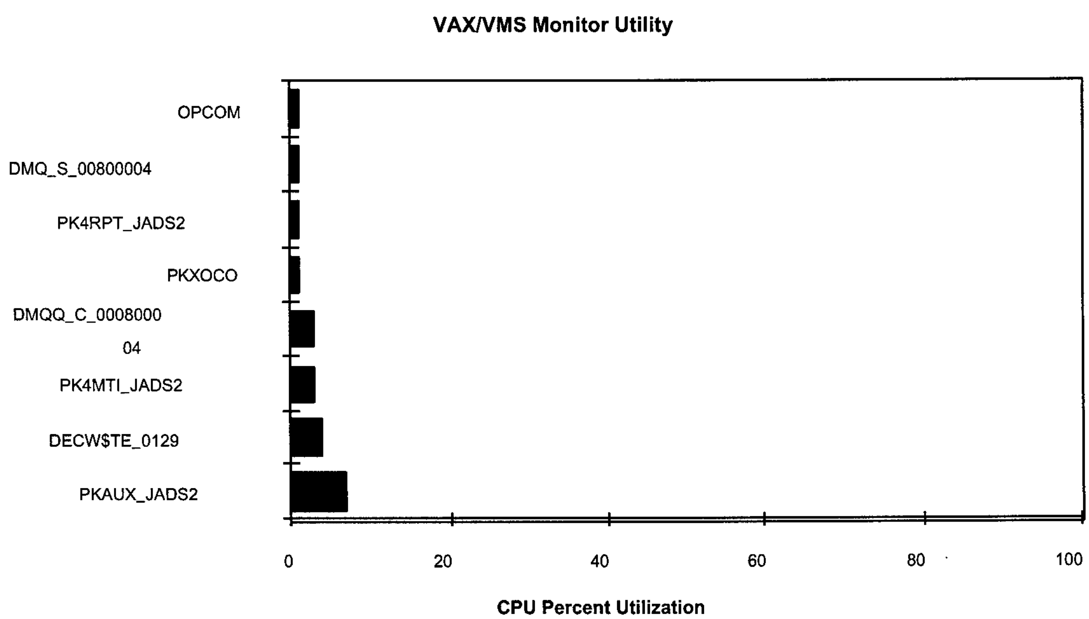

Figure 5-3 Standard Scenario Candidate 2 RDP CPU Utilization

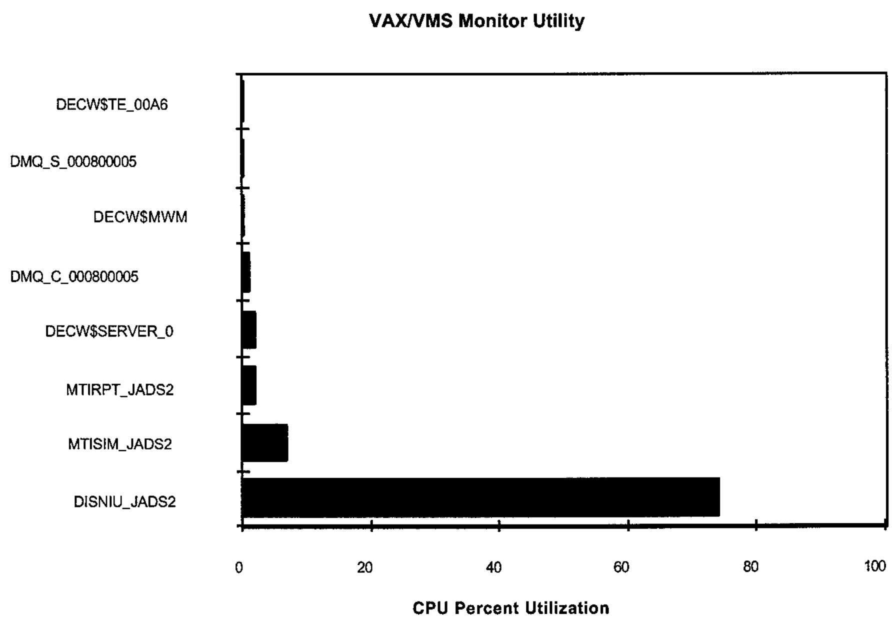

Figure 5-4 Standard Scenario Candidate 2 Spare GPC CPU Utilization

5.3.4 Modification of Existing Software Candidate Two

The new software modules which will be required to be developed for candidate number two are shown in Tables ~\ref{sw_new_rpt_one}, \ref{sw_new_sim_two} and \ref{sw_new_dis_two}.

\input{new_code_c2_rpt_table.tex}
\input{new_code_c2_sim_table.tex}
\input{new_code_c2_dis_table.tex}

The estimated modified lines of code for candidate number two is summarized in Table 5-4.

PK4RPT Process		
Software Module	**Function**	**Lines of Code**
SKRP01_MTI_REPORT	Main program unit for this process.	3
SKRP02_INIT_REPORT	Initializes the PK4RPT process to JSTARS s/w. with JADS	32
SKRP05_RETRIEVE_DATA	Receives incoming messages. Modified to receive the RPT_TEST_ PARAMS_CQ message from the MTIRPT process.	14
SKRP08_DATA_TO_OCO	Sends the final MTI report onto the MTI DATA MOT queue. Modified to send the Live MTI data to the spare GPC.	33
SKRP99_SHUTDOWN	Dumps Timing data to file whenever PK4RPT shuts down	52
	PK4RPT Totals:	134
PK2MCP Process		
SK2M11_PROCESS_MOCOMP_DATA	Receives incoming messages. Modified to receive the MCP_TEST_ PARAMS message from the MTIRPT process.	2
SK2M_BLD_MTI_PSP_PARAM_MSG	Builds and sends the MTI_PARAMETERS message to the PSPs. Modified to send this message to the MTISIM process for the first CPI in a dwell as well as send to the PSPs.	6
	PK2MCP Totals:	8
Total Modified lines		142

Table 5-4 Estimated Modified Lines of Code Candidate Number Two

5.3.5 Modification or Addition of Hardware Candidate Two

Candidate number two does not require the modification or addition of any hardware components to the JSTARS system.

5.3.6 Use of Existing Simulations and Models Candidate Two

Candidate number two uses the screening code and coordinate conversion code which was developed during the Joint STARS FSD program.

5.3.7 Level of Simulation Candidate Two

The RPS candidate number two is implemented at the RADAR report level. This means that all the MTI target detection, target classification, and location accuracy processing are simulated by the RPS.

5.3.8 Integration Complexity Candidate Two

The integration complexity of candidate two is low because the RPS is well partitioned from the JOINT STARS prime mission equipment (PME) software. During integration data flow can be monitored between processes on an external interface. This will be possible using standard JOINT STARS recording equipment.

5.3.9 Expandability/Growth Candidate Two

The expandability of RPS candidate number two is limited only by the existing memory capability and processing speed of the Spare GPC. This is true due to the fact that candidate number two only effects the MTI report delivery time to the O\&C subsystem which will not be detectable by the operator.

5.4 Trade Study Results Candidate Three

The following paragraphs describe the performance expected for candidate number three.

5.4.1 Timeline Impact Candidate Three

The timing results presented here will be of a relative nature only since the actual RADAR timeline is a very complex non-linear function of target loading. The estimated timing for candidate number three is summarized in Table ~\ref{time_three_10hz}.

\input{sw_time_c3_10hz.tex}

5.4.2 Memory Requirements Candidate Three}

The memory requirements presented here will be of a relative nature only since the actual RADAR memory utilization is target dependent. The baseline SPARE GPC memory utilization is zero during normal RADAR operation. The estimated SPARE GPC memory utilization for candidate number three is summarized in Table ~\ref{memory_three}.

\input{sw_memory_c3.tex}

5.4.3 System Loading Candidate Three

A typical CPU utilization plot for candidate number three is shown in Figure 5-5 for the RDP processes and Figure 5-6 for the Spare GPC processes. The JADS DIS process takes most of the available CPU with an average GPC CPU utilization of 75\% for this case.

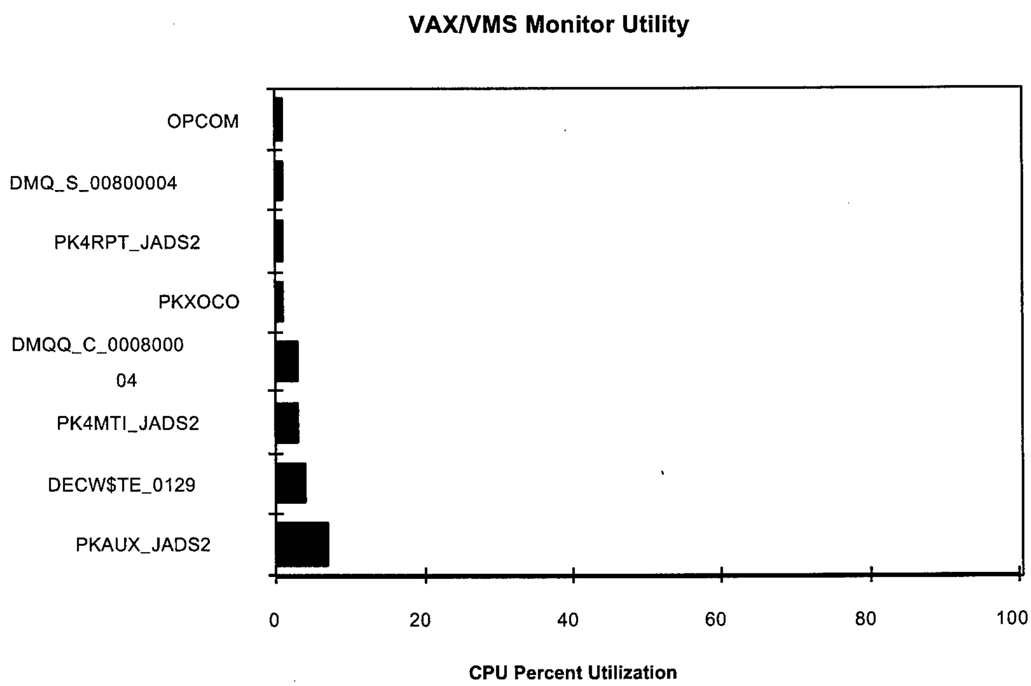

Figure 5-5 Standard Scenario Candidate 3 RDP CPU Utilization

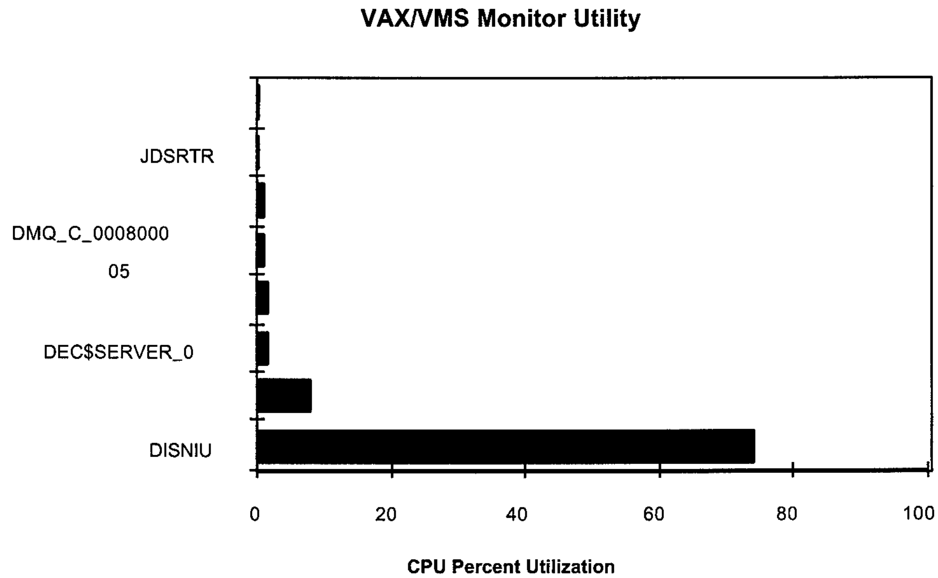

Figure 5-6 Standard Scenario Candidate 3 Spare GPC CPU Utilization

5.4.4 Modification of Existing Software Candidate Three

The new software modules which will be required to be developed for candidate number three are shown in Tables ~\ref{sw_new_JDSND1_three}, \ref{sw_new_sim_three} and \ref{sw_new_dis_three}. The estimated modified lines of code for candidate number three is summarized in Table ~\ref{sw_mod_three_ncp}.

\input{new_code_c3_JDSND1_table.tex}
\input{new_code_c3_sim_table.tex

JADS DISNIU PROCESS		
Software Module	**Function**	**Lines of Code**
DISNIU_Fill	Simulates Reception of DIS PDUs	60
DISNIU_FILTER_PDUs	Filters Entity State PDUs	36
DISNIU_Main	Init socket interface receive msg from DIS LAN maps to MTISIM common DB performs dead reckoning	180
DISNIU_REPORT	Dumps PDU DataBase Time numbers to file	21
DISNIU_DR_Report	Dumps dead reckoning timing numbers to file	20
Init_Topo	init topo origin	10
Geoc_To_Topoc	convert from Geo to Topo coordinates	10
Topoc_To_Geoc	convert from Topo to Geo coordinates	10
Geod_To_Geoc	convert from Geod to Geo coordinates	8
Byte_Swap_Lword	byte swap 4 byte word	10
Byte_Swap_Word	byte swap 2 byte word	8
Lword_Swap_To_Dword	byte swap 8 byte word	7
VAX2IEEE_Init	VAX to IEEE initialize	3
VAX2IEEE_Short	VAX to IEEE single prec	3
VAX2IEEE_Float	VAX to IEEE Float point	4
VAX2IEEE_Double	VAX to IEEE double prec	5
CVT_DIEEE_TO_DVF	converts little endian/ IEEE value to VAX value	12
CVT_DVF_TO_DIEEE	converts VAX value to little endian/IEEE value	11
CVT_IEEE_TO_VF	converts little endian/ IEEE value to VAX value	10
CVT_VF_TO_IEEE	converts VAX value to little endian/IEEE value	10
DISNIU Totals:		**438**

Table 5-5Estimated New Lines of Code Candidate Number Three cont'd

PTNOWA Process		
Software Module	Function	Lines of Code
Main	Main program unit for this process.	222

PTNOWA Totals:	222

Table 5-6 Estimated Modified Lines of Code Candidate Number Three

5.4.5 Modification or Addition of Hardware Candidate Three

Candidate number three does not require the modification or addition of any hardware components to the JSTARS system.

5.4.6 Use of Existing Simulations and Models Candidate Three

The level at which candidate number three injects the virtual targets requires that all new models and simulations be developed.

5.4.7 Level of Simulation Candidate Three

The RPS candidate number three is implemented at the RADAR CPI level. This means that all the target classification, and location accuracy processing are simulated by the RPS.

5.4.8 Integration Complexity Candidate Three

The integration complexity of candidate three is lower than candidate number one because the RPS is well partitioned from the JOINT STARS prime mission equipment (PME) software. During integration we will be able to monitor data flow between processes on an external interface. This will be possible using our standard JOINT STARS recording equipment. However, the complexity is greater than candidate number two because of the content and volume of the message data transferred between processors.

5.4.9 Expandability/Growth Candidate Three

The expandability of RPS candidate number three is limited by the existing memory capability and processing speed of the Spare GPC. The candidate number three software must handle every Node 1 message and therefore by it's very nature impact the RADAR timeline. This timeline effect will be noticeable under full target load.

6 Trade Study Conclusions

The following paragraphs comprise the results of the architectural trade study for the JADS RPS. An overall summary of the trade study results are given in Table 6-1.

			Candidate	
Criterion	Weight	Number 1	Number 2	Number 3
Timeline Impact	10	2	3	1
Memory Requirements	2	1	3	2
System Loading	8	1	3	2
Modification of Existing Software	9	1	2	3
Modification or Addition of Hardware	6	3	3	3
Use of Existing Simulations and Models	4	3	3	3
Level of Simulation	4	2	2	3
Integration Complexity	5	1	2	2
Expandibility/Growth	6	1	3	3
Total		88	144	127

Table 6-1 Evaluation Results Summary

Candidate number two is the clear choice for the JADS implementation in the JOINT STARS system. It is low risk with acceptable performance. The following general conclusions can be drawn from the architectural study.

- Candidate number one has the most undesirable effect of being able to limit the radar's performance due to timeline, memory and CPU utilization.
- Candidate number two has the least impact on radar performance. The delay that is incurred in this candidate is only a delay in delivery of the reports to the operator and as such does not impact radar timeline or performance.
- Candidate number three has more of an advantage from a testing stand point in that it can be used to throughly test the Radar Data Processor processes. It can however, under full target load have a severe effect on the radar timeline.

APPENDIX B

Engineering Design Report

for the

Radar Processor Simulation

for the

Joint Surveillance Target Attack Radar System (Joint STARS)

DOCUMENT NO. JADS-RPT-002
CODE IDENT: Q003
DATE May 1996

ENGINEERING DESIGN REPORT FOR THE RADAR PROCESSOR SIMULATION FOR THE JOINT SURVEILLANCE TARGET ATTACK RADAR SYSTEM (JOINT STARS)

CONTRACT NO. F19628-94-C-0040

Prepared for:
Department of the Air Force
Headquaters Electronics System Center
Hanscom Air Force Base, Massachusetts 01731

Prepared by:
Northrop Grumman
2000 W. Nasa Blvd.
Melbourne, Florida 32901

W. Moore Date Director, Systems Engineering	Dr. A. Bramson Date JADS Program Manager
Joe Lee Date JADS Team Leader	H. Berman JADS Engineering Manager
Richard Floto Date Cognizant Engineer	

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1. Scope

This document establishes the hardware and software requirements to meet the system design goals for the Radar Processor Simulation (RPS) being developed for the purposes of integrating Joint-STARS into a Joint Advanced Distributed Simulation (JADS) environment. The requirements specified in this document are for those techniques specific to the development of the RPS in the JADS environment. Algorithms and techniques developed for Joint STARS are referenced in this document, but are not specified in detail. A typical JADS environment is shown I Figure 1.-1.

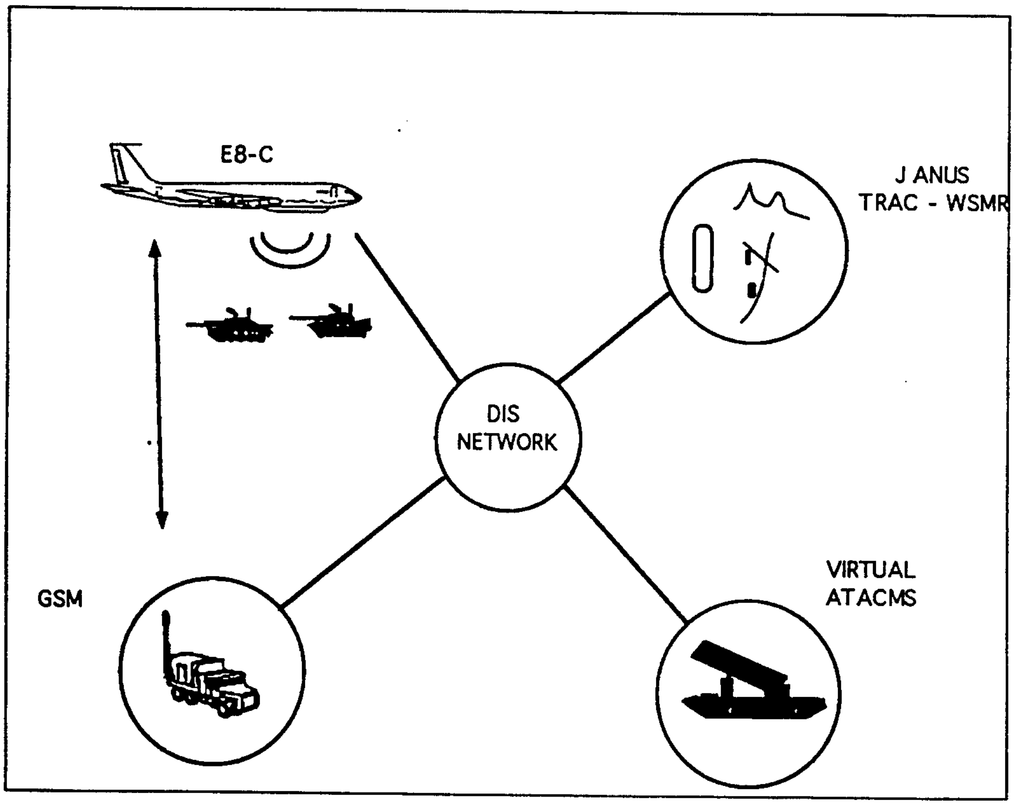

Figure 1.-1. Typical JADS Environment

The general concept of operation for Joint STARS within such an environment is as follows:

- The Joint STARS aircraft will fly over a government controlled facility (such as Ft. Irwin)
- A small area will contain controlled targets, tanks, trucks, etc.

- A target / war simulation such as JANUS will be operating at a government facility such as White Sands Missile Range (WSMR) generating virtual targets and issuing Protocol Data Units (PDUs) on the Distributed Interactive Simulation (DIS) network

- The RPS will receive the virtual target information, from the DIS network via entity state PDUs and supply virtual target radar reports combined with the live target radar reports

Figure 1.-2 is a block diagram for Joint STARS identifying the functional layout of its five subsystems; (1) Operations and Control; (2) Data Link; (3) Communications; (4) Radar; and (5) Aircraft Subsystems.

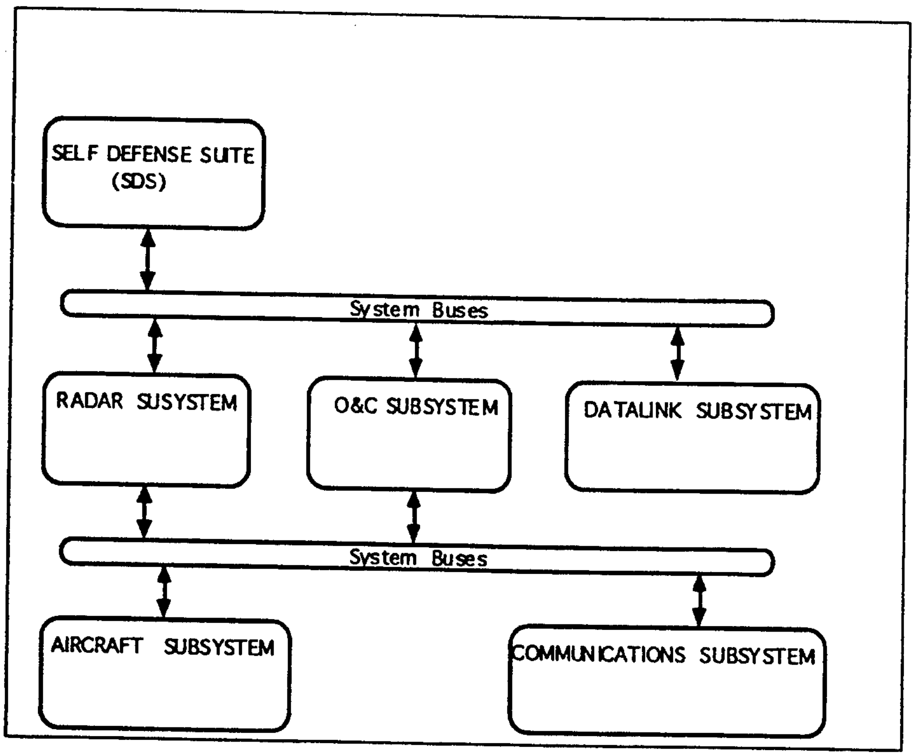

Figure 1.-2. Joint STARS System Block Diagram

The Architectural Design Report (JADS-RPT-001) referenced in section 2 proprosed three candidate architectures to implement the RPS within Joint STARS. One of the primary design goals presented in the Architecture Design Report is minimizing modification to existing Joint STARS software. With this goal in mind, all three candidates were designed using similar algorithms and techniques which required little or no software modifications. Since the algorithms used by the candidates are very similar, the software requirements which drive the algorithms tend to transcend a specific architecture, so that this

design report may assume that any of the candidate architectures will be selected for implementation of the RPS.

2. Applicable Documents

The following is a list of the applicable documents.

Document Name	Date of Issue	Revision
Engineering Services Task (EST) Statement of Work E-8C RADAR Processor Simulation		
System Specification For Joint Surveillance Target Attack RADAR System AN/USY-TBD (JOINT STARS)	21 December 1992	
Prime Item Development Specification For RADAR Subsystem AN/APY-(TBD) For Joint Surveillance Target Attack RADAR System (JOINT STARS)	12 June 1991	
Architecture Design Report for the RADAR Processor Simulation for the Joint Surveillance Target Attack RADAR System (JOINT STARS)	March 1996	
Standard for Distributive Interactive Simulation - Application Protocols Version 2.0.4	16 March 1994	
Security Classification Guide Joint STARS Version 2.0.4	9 March 1994	
Interface Control Document for the SAR Imagery Simulation of the Joint STARS Radar Processor Simulation	TBD	

3. Requirements

The hardware and software requirements specific to the development of the RPS within Joint STARS will be presented in this section.

3.1 Hardware Requirements

This section presents the hardware requirements for the incorporation of the RPS into the Joint STARS system. Since one of the primary system design goals for the RPS is to limit, if not eliminate, hardware modifications to the Joint STARS system, there are few hardware requirements placed on implementation of the RPS. Under normal conditions, the RPS shall [1] consist of two distinct architectures, one on the ground (3.1.3) interfacing with the DIS network, and one on-board the Joint STARS platform (3.1.4) performing the MTI and SAR Imagery simulations. These two architectures shall [2] be connected by an RF Link (3.1.2) during flight mode and with a LAN while in the lab environment.

3.1.1 Joint STARS Configuration

The RPS shall [3] be developed for incorporation into the third aircraft configuration used for low rate initial production of the E-8C Joint STARS.

3.1.2 RF Link

The bandwidth requirements for the RF Link will be developed during the detailed design phase of the RPS from message load tests with the assistance of the JADS JTF.

3.1.3 Down Link Architecture

The down link processes developed for the RPS will be hosted in a general purpose computer capable of processing the maximum PDU rates and capacities specified in 3.2.1.3. The down link architecture shall [4] be capable of logging PDUs for future data analysis and test purposes.

3.1.4 Up Link Architecture

The up link processes developed for the RPS shall [5] be hosted in one or more of the Joint STARS general purpose computers (GPC) on board the platform. The JADS Architectural Design Report identifies the RDP GPC, SPR GPC, and the ATWS as possible candidates for hosting the up link RPS architecture.

3.2 Software Requirements

This section presents the software requirements for four functional levels of the system design; (1) RPS control; (2) MTI Simulation; (3) SAR Imagery Simulation; (4) and Stand Alone operations.

3.2.1 RPS Control

The RPS control function will provide the interface between the Joint STARS functions, the RPS functions and the external JADS environment. Within the RPS, the control function will provide the MTI (3.2.2) and SAR Imagery (3.2.3) simulation with the appropriate Joint STARS data and external JADS data to perform their functionality.

3.2.1.1 Initialization

The RPS will be initialized with the data described in this section.

3.2.1.1.1 Identify Live AOIs

A live area of interest (LAOI) is defined as a rectangular region of interest entirely located within the 512-by-512 Km primary region of interest. Within these LAOIs, only "live" targets detected by Joint STARS shall [6] be reported. Outside of these LAOIs, only "virtual" targets supplied to the RPS shall [7] be reported. The RPS shall [8] maintain up to four LAOIs. The set of LAOIs shall [9] be provided by the customer as a file to be read in upon initialization of the RPS and cannot be modified during the JADS exercise.

3.2.1.1.2 Identify Hypso and Carto Database

The hypsographic and cartographic databases defining the features of the Joint STARS primary region shall [10] be replaced upon initialization of the RPS with a new set of databases incorporating the virtual features for the JADS mission. These databases will be the same format as those used for the Joint STARS mission and will be supplied by the customer. For SAR Imagery, a SAR features database will be developed and supplied by the customer.

3.2.1.2 Operator Controls

The RPS operator shall [11] be given modest control of simulation parameters through the use of flags and thresholds. The set of modifiable parameters will be at least, but not limited to the following:

- Enable / Disable MTI Pd

    - If enabled, minimum and maximum Pd. (Pd = 1 if disabled)

- Enable / Disable MTI CEP

  - If enabled, maximum down range and cross range error. (CEP = 0 if disabled)

- Enable / Disable MTI Terrain Screening

- Enable / Disable MTI False Alarms

- Weather conditions as Clear, Cloud, or Rain

- Joint STARS Entity State (ES) Protocol Data Unit (PDU) Heartbeat Period

- Joint STARS ES PDU Platform Position Update Threshold

3.2.1.3 DIS Interface Control

The RPS control function shall [12] receive ES PDUs over the DIS network and maintain a database of those ES PDUs applicable to the Joint STARS mission.

3.2.1.3.1 DIS Network

ES PDUs shall [13] be managed in two separate architectures, one on the ground connected to the DIS network, referred to as DISNIU I, and a second on the platform connected to the Joint STARS OWS and / or PSP LAN, referred to as DISNIU II. When operating in flight mode, they will be connected by an RF link. When operating in a lab environment, they will be connected with a LAN. DISNIU I shall [14] use the TCP/IP UDP protocol for communication on the DIS network.

3.2.1.3.2 Receive Entity State PDUs

The Entity State (ES) Protocol Data Unit (PDU) is the primary type required to be acted upon by the RPS. ES PDUs contain information about a particular entity as described in the DIS standard (2.). An entity can be any object such as a tank, a truck, an aircraft, a bridge, a building, etc…, and is considered a virtual target by the RPS. The RPS will receive new ES PDUs by the war-games simulation, followed by a periodic "heartbeat" ES PDU for each entity to affirm reception by the RPS. Virtual target updates will be received by the RPS via ES PDUs when the position of the virtual target has exceeded the pre-determined threshold based on dead reckoning (3.2.1.3.5) updates by the war-games simulation. The RPS shall [15] be required to maintain at least 5000 virtual targets, with a growth capacity of at least 20000 virtual targets. Virtual targets shall [16] be deleted by the RPS when the war-games simulation issues a Remove Entity PDU or if "deactivated" by an ES PDU.

3.2.1.3.3 Coordinate Conversion

ES PDUs received over the DIS network contain position and velocity information in the Earth-Centered-Earth-Fixed (ECEF) coordinate system using the 1984 World Geographic System earth model (WGS-84). ES PDU position and velocity shall [17] be converted from ECEF to the Joint STARS Topocentric Coordinate System (TCS) by SIDNIU I in order to save processor load for the real-time MTI (3.2.2) and SAR Imagery (3.2.3) simulations on the platform. ES PDU orientation shall [18] be converted from the entity coordinate system to TCS by DISNIU I.

3.2.1.3.4 Filter Entity State PDUs

ES PDU information applicable to the MTI and SAR Imagery simulations shall [19] be reduced to the minimum amount of information required by the real-time simulations in order to minimize the use of the available RF Link bandwidth. As a minimum, the ES PDUs will be reduced to a virtual entity described by its unique identifier, entity type, time tag, position, velocity, orientation, and appearance. Currently, ES PDUs will be received from a single source, so that identification of each ES PDU may be accomplished using a unique entity ID (SITE = APPLICATION). The software design should accommodate multiple sites and applications as a growth provision.

ES PDU filtering shall [20] be performed on a maximum sustained rate of 100 virtual target updates per second plus the heartbeat rate. After DISNIU I has coordinate converted and reduced the ES PDU to its minimum length, the virtual target updates will be sent up the RF Link to the DISNIU II. If the currently undefined RF Link bandwidth cannot support the virtual target update rate, then further data compression may be required along with a geometrical filter placed around existing RSR AOIs to reducr the number of virtual target updates sent over the RF Link. If a geometrical filter is necessary, the virtual target dead reckoning (3.2.1.3.5) will also be required in DISNIU I.

3.2.1.3.5 Dead Reckoning

Virtual targets received by DISNIU II shall [21] be extrapolated to current time at a minimum rate of 5 Hz using a first order position update ($P = P_0 + V\Delta T$). Timing studies in the Architectural Design Report indicate that first order target dead reckoning does not adversely effect the radar timeline even when the number of targets exceeds the current virtual target capacity. Dead reckoned virtual targets will be make available to the MTI (3.2.2) and SAR Imagery (3.2.3) simulations.

3.2.1.3.6 Joint STARS Entity State PDU

DISNIU II will send state information about the Joint STARS Platform, including position and velocity, down the RF Link to DISNIU I, which will be converted to an ES PDU and output over the DIS network. The Joint STARS state message shall [22] be sent at a 1 Hz rate by DISNIU II and output over the DIS network by DISNIU I when the dead reckoned platform position varies by more than the operator specified Joint STARS position threshold, or its heartbeat timer has expired.

3.2.1.4 Live Target Control

The RPS will provide the MTI Simulation (3.2.2) those targets detected by the Joint STARS radar for the current radar beam dwell. Depending upon the architecture selected, these "live" targets may be provided as threshold crossings on a coherent processing interval (CPI) basis, or as associated targets on a beam dwell basis.

3.2.2 MTI Simulation

The MTI simulation will receive as input from the RPS control function (3.2.1) the current beam dwell's live targets and the moving virtual targets received form the DIS interface. The virtual targets shall [23] be geometrically filtered, have MTI statistics applied, and mixed with the appropriate live targets for output from the radar subsystem. The processing required by the MTI simulation shall [24] not degrade the radar timeline beyond the nominal timeline fluctuations experienced by the Joint STARS radar under heavy target load conditions.

3.2.2.1 MTI Control

The MTI control function shall [25] determine those virtual targets within the current beam dwell footprint but not within the LAOIs.

3.2.2.1.1 Reverse Area Blanking

For each radar coherent processing interval (CPI), those range bins which interact one or more of the LAOIs will be identified for consideration of live targets. Range bins which do not intersect an LAOI will be identified for consideration of virtual targets.

3.2.2.1.2 Beam Dwell Footprint

For each radar beam dwell, a beam footprint will be determined from the initial cone angle, range coverage, and beamwidth parameters provided in the radar AUX data. The radar AUX data is available within several messages throughout the radar subsystem. The beam footprint will be approximated as a quadrilateral in the Topocentric Coordinate System (TCS) for easy comparison with live and virtual targets already defined in TCS. For each Radar Service Request (RSR) actively being scanned, the beam dwell footprints will be contiguously maintained without overlap until a start of revisit, start of swath, or a resumption of revisit condition occurs, for which a complete footprint must be computed.

3.2.2.1.3 Filter Live Targets

Targets detected by the Joint STARS radar will be considered "live" targets. Only those live targets which reside inside a LAOI shall [26] be considered "detected" by the RPS. All live targets which reside outside the LAOIs (aka virtual area) will not be considered a detected target by the RPS. Live targets being filtered on a CPI basis will only be considered if they fall within the LAOI range bins determined in reverse area blanking (3.2.2.1.1).

3.2.2.1.4 Filter Virtual Targets

Moving targets within the entity database will be considered "virtual" targets. Only those virtual targets which reside outside the LAOIs (aka virtual area) and within the current radar beam dwell footprint shall [27] be considered for possible "detection" by the RPS. The MTI processing (3.2.2.2) function will determine which virtual targets will actually by detected. Timing studies in the Architectural Design Report indicate that virtual target filtering for conditions exceeding the current virtual target capacity adversely effects the radar timeline. For these conditions, a grid filtering technique shows some promise for reducing the radar timeline to a manageable level. The grid filtering technique requires the virtual targets to be pre-sorted into a series of X-Y grids which can be quickly checked against the radar beam footprint, thereby quickly eliminating a significant number of virtual targets from consideration. The goal of this tradeoff wouldbe to define the grid size to minimize the number of grids plus targets to check against the radar beam footprint and minimize the management overhead of the grid structure.

3.2.2.1.5 Mix Live and Virtual Targets

For each radar beam dwell, the detected live moving targets (3.2.2.1.3) and the detected virtual moving targets (3.2.2.2) shall [28] be merged into a single dwell report representing a mix of live and virtual targets within the same beam, but not overlapping in physical space. Depending upon the selected architecture, this functionality may be achieved prior to, or after, target association occurs within the RDO post processing function.

3.2.2.2 MTI Processing

After the MTI control function (3.2.2.1) filters the virtual targets based on beam dwell and LAOI geometry, this simulation shall [29] create a subset of these virtual targets which exhibit similar characteristics as live Joint STARS targets would under the same scan conditions. These virtual targets will have moving target indicator statistics applied and will be output to the MTI control function to be mixed with the appropriate live targets detected in the same beam.

3.2.2.2.1 Beam Dwell

The radar beam's range coverage, azimuth, and 3dB dwell time will be derived for each beam dwell from the radar AUX data. The radar beam's range coverage extends the specified number of range bins from the range start value adjusted by the radar zero range delay and range refraction correction. The radar beam azimuth coverage is defined by the cosine cone angle term and the specified beam spacing. The radar dwell time is derived from the radar pulse repetition interval (PRI), the number of

integrated pulses, and the waveform identifier. Since the Joint STARS radar uses variable beam spacing, the dwell time will be normalized to the 3dB spacing using the azimuth angle and the actual beam spacing commanded. The waveform identifier indicates the PRFs used in the beam dwell.

3.2.2.2.2 Environmental Conditions

Applicable external environmental conditions will be considered to effectively model moving targets.

3.2.2.2.2.1 Weather

Weather conditions shall [30] be assumed to be one of three categories; (1) clear; (2) cloud; (3) rain; as defined in the Joint STARS System Specification, as selected by the JADS operator (3.2.1.2). Future considerations should be made for incorporation of weather PDUs defining regions of weather coverage. From the selected weather condition, an additional signal-to-noise (S/N) variation over the range coverage will be computed for use by the Pd (3.2.2.2.3.5) and location accuracy (3.2.2.2.3.3) functions. The additional S/N loss will be determined based on the Joint STARS System Specification losses for each weather condition.

3.2.2.2.2.2 Refraction

A range refraction curve will be derived for the range coverage of each beam dwell and applied to the down range target statistics for location accuracy (3.2.2.2.3.3). The method employed by Joint STARS to determine the range refraction correction shall [31] be used by the RPS to enhance symmetry between live and virtual targets.

3.2.2.2.2.3 Terrain

The RPS shall [32] identify those virtual targets obscured by terrain based on the hypsographic database, and the current platform position along the radar beam's line of sight. As indicated in figure 3.2-1, when the elevation of the target to the platform is less than the elevation of the target to the highest grid point along the beam's line of sight, then that target is considered screened by the terrain and not eligible for detection.

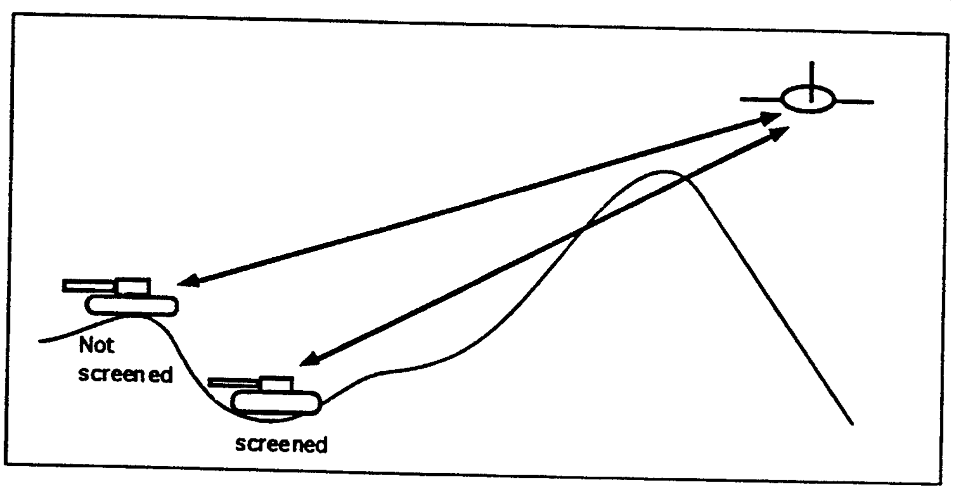

Figure 3.2-1. Terrain Screening

3.2.2.2.3 Virtual Target Statistics

MTI statistics shall [33] be applied stochastically to the virtual targets using a uniformly distributed random number sequence in order to effectively simulate virtual targets as Joint STARS targets. All virtual target statistics will be derived from a single random number seed.

3.2.2.2.3.1 Virtual Target Geometry

The MTI Control function (3.2.2.1) will provide those virtual targets to be considered for MTI processing. These targets have been dead reckoned to the current beam dwell time and as a minimum are represented by its target position (P_t) and velocity (V_t) vectors in TCS. P_t and V_t represent the ground truth of the target for which MTI statistics will be applied. Each target's ground truth will be converted to radar coordinates of range, azimuth, and radial velocity.

3.2.2.2.3.2 Radar Cross Section

The RPS will use a nominal sized target defined in the Joint STARS System Specification. Virtual target amplitudes will vary as a function of range with random fluctuations within a 5dB tolerance interval.

3.2.2.2.3.3 Location Accuracy

Target location accuracy is measured using the Circular Error Probable (CEP) method with separate down and cross range errors assumed to be uncorrelated forming a linear error model shown in figure 3.2-2. S/N variations due to weather and range will be modeled for determination of the one sigma cross range component in the linear model. Amplitude and frequency modulation techniques will be applied to the mean and one sigma error statistics to prevent integrated targets from looking too "simulation-like". These modulation techniques have the effect of moving a smaller CEP circle within a larger CEP circle to achieve the same CEP results with fewer unrealistic random fluctuations. Once the down range and cross range error has been established, these values shall [34] be applied to the position vector (P_t) of the target. The down range error is applied in the TCS X-Y plane along the beam's line of sight to the target, while the cross range error is applied perpendicular to the beam's line of sight to the target.

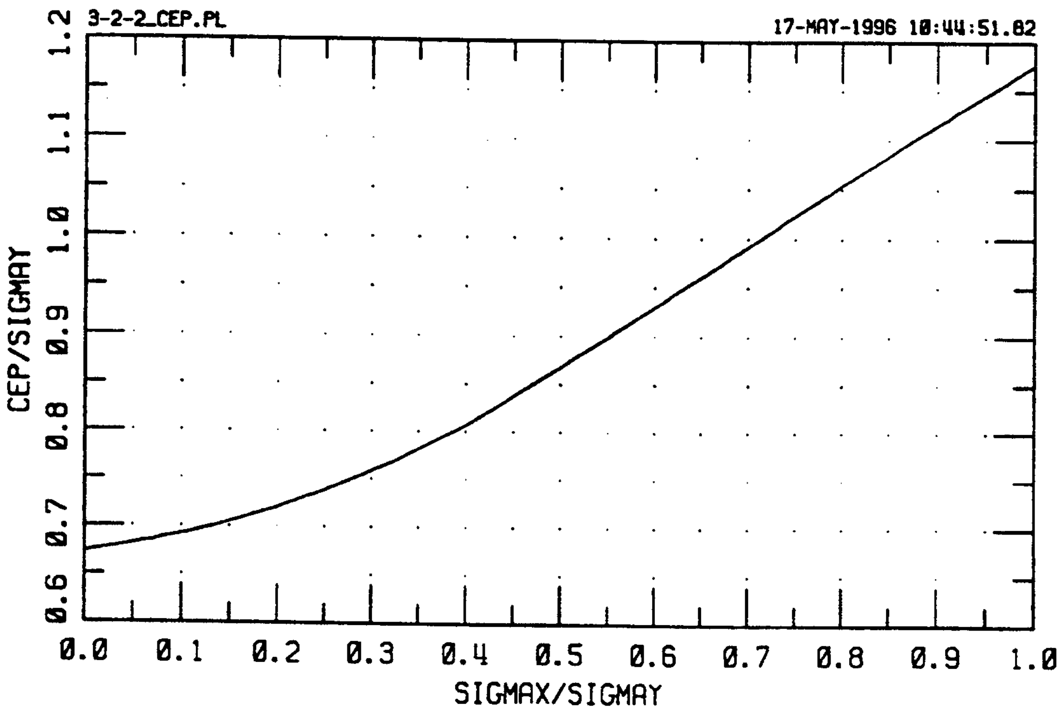

Figure 3.2-2. Circular Error Probable (CEP)

3.2.2.2.3.4 Target Resolution

Multiple targets located within the same range / doppler cell cannot be distinguished from each other, so that Joint STARS range, velocity and angle resolution constraints will be applied to target detection statistics. If multiple targets cannot be distinguished, then only one target may be detected.

3.2.2.2.3.5 Probability of Detection (Pd)

The average Pd of a target (Pd_t) is fundamentally related to target S/N as derived from the radar range equation. The Joint STARS radar is designed to compensate for two major S/N factors in real time by varying the radar beam dwell time as a function of azimuth and range. These S/N factors are azimuth beam broadening losses resulting from steering the beam electronically in azimuth, and target range loss. Radar operating curves (3.2.2.2.4) shall [35] be developed off line which relate the radar beam dwell time to the Joint STARS azimuth (figure 3.2-3) and range (figure 3.2-4) constraints for a family of Pd and S/N levels. Analysis has shown that these curves are reasonably well behaved and can be modeled using a Lagrange interpolation series of four points.

The Lagrange interpolation coefficients can be expanded in azimuth and range to derive the theoretical 3dB dwell times for various average Pd levels, from which Pd_t can be interpolated based on the actual 3dB dwell time produced by the radar scan. This technique effectively reverses the Joint STARS engineering process of solving for dwell time given a desired Pd. Once Pd_t is found, radial velocity dips

due to PRF blinds will be applied. The RPS shall [36] have a Pd versus radial velocity curve (figure 3.2-5) for each waveform identifier developed off line as per section (3.2.2.2.4). Since the structure of the radial velocity dips do not change for various Pd levels, the actual target Pd (Pd_t) will be determined for Pd_t and the Pd versus radial velocity curve, by effectively moving the curve up or down so that its average Pd is the same as Pd_t. The radial velocity Pd dips are attenuated when increasing the average Pd and enhanced when reducing the average Pd through use of a range rate dip factor (R_f).

As a minimum, virtual target Pd (Pd_t) shall [37] be derived from the following information:

- Scan conditions (3.2.2.2.1)

  - Azimuth : expand dwell time by azimuth, figure 3.2-3.
  - Range coverage : expand dwell time by range, figure 3.2-4.
  - 3dB beam dwell time : apply Pd factor to dwell time, figure 3.2-5.
  - Waveform identifier : select nominal Pd vs Velocity curve, figure 3.2-6.

- Environmental factors (3.2.2.2.2)

  - Weather loss : interpolate Lagrange coefficients between S/N levels.
  - Terrain : targets obscured by terrain cannot be detected (Pd = 0).

- Virtual target geometry (3.2.2.2.3.1)

  - Azimuth : for Pd purposes, target azimuth may be assumed to be the same as beam dwell azimuth, since the azimuth beamwidth is relatively small.
  - Range : solve for dwell time based on range coverage curve, figure 3.2-4.
  - Radial velocity : $Pd_t = Pd_t + R_f \times (Pd_{rt} - Pd_r)$
    * Pd_t is the Pd of the virtual target at radial velocity V.
    * Pd_t is the Pd of the virtual target averaged over all radial velocities.
    * R_f is the range rate factor used to attenuate / enhance Pd dips.
    * Pd_{rt} is the Pd of the reference curve at radial velocity V.
    * Pd_r is the Pd of the reference curve averaged over all radial velocities.

- Target resolution (3.2.2.2.3.4)

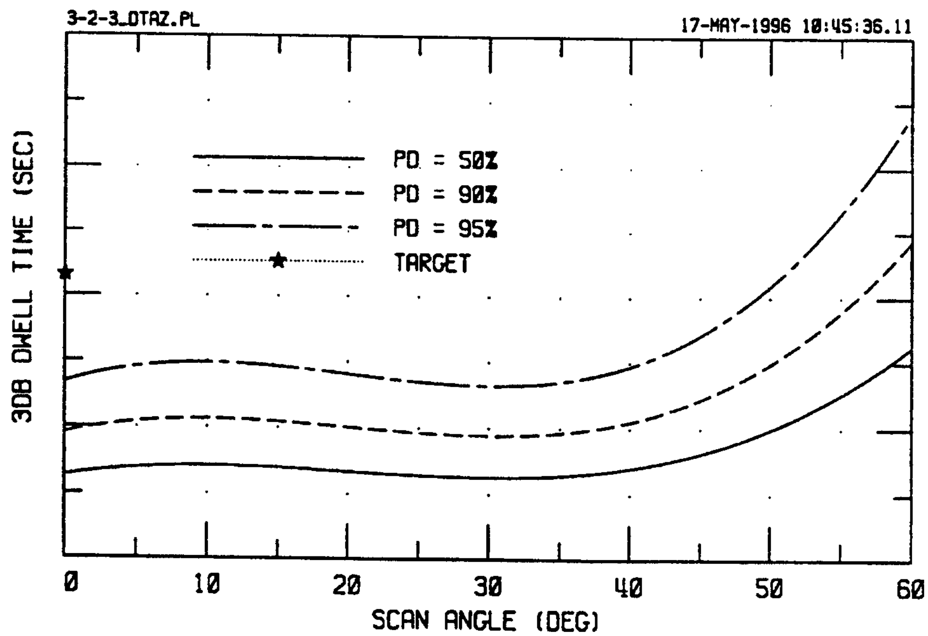

Figure 3.2-3. Expand Dwell Time by Azimuth (at Minimum Range)

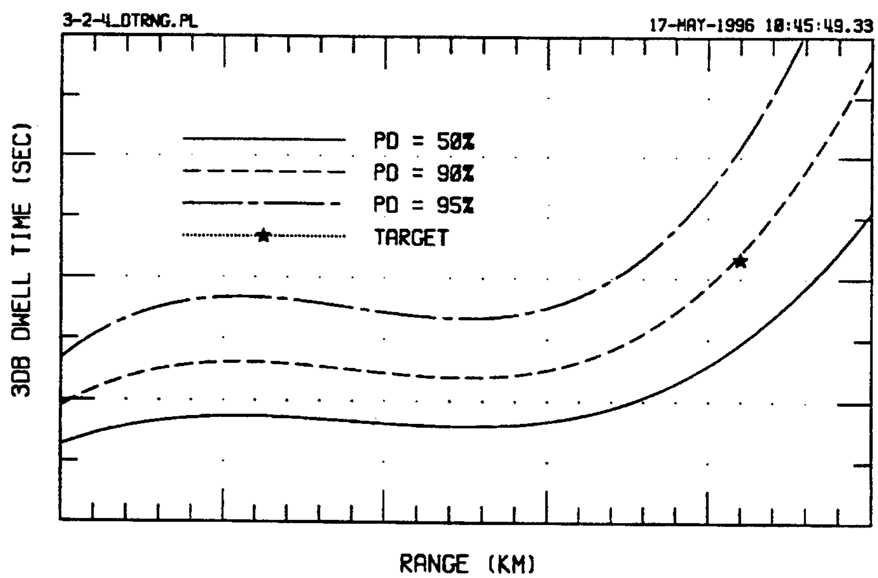

Figure 3.2-4. Expand Dwell Time by Range (at Dwell Azimuth)

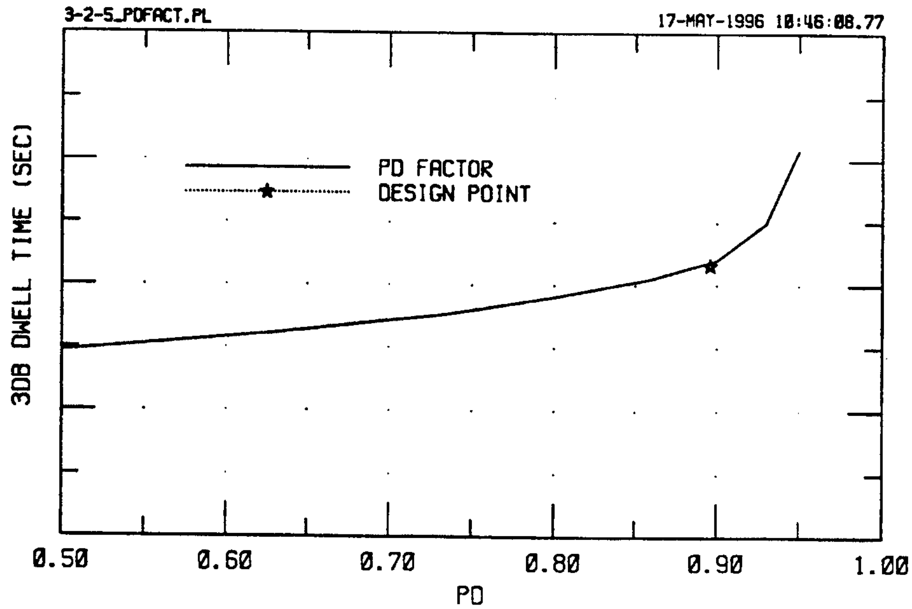

Figure 3.2-5. Apply Pd Factor to Dwell Time

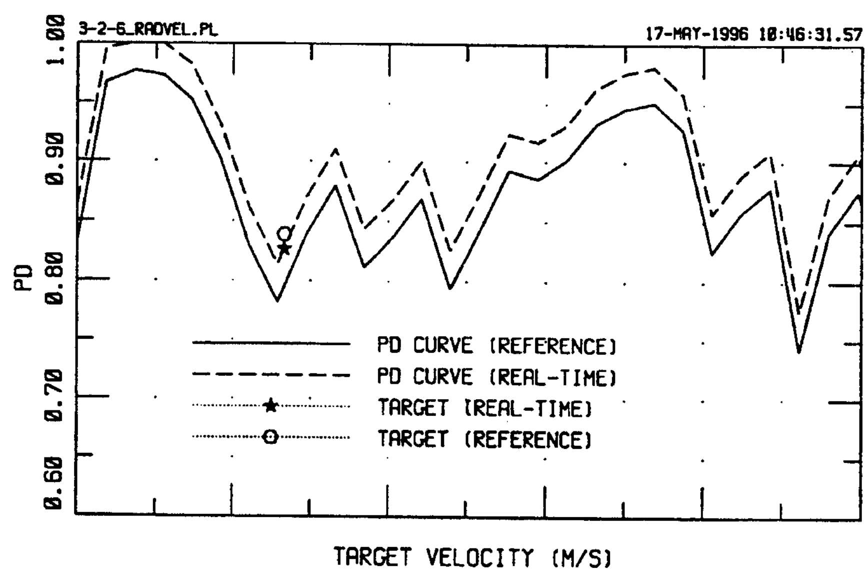

Figure 3.2-6. Apply Radial Velocity Dips

3.2.2.2.3.6 Probability of False Alarm (PFA)

RSR receiver threshold levels shall [38] be considered to increase or decrease the nominal PFA required by the Joint STARS System Specification. False virtual targets will be placed randomly in range and azimuth within the radar beam dwell (3.2.2.2.1) after all virtual targets have been considered.

3.2.2.2.3.7 Target Classification (TC)

A TC of wheeled or tracked will be determined based on the probability of detecting the double doppler component. Since the double doppler component is significantly smaller than the actual target, determination of virtual target TC shall [39] be accomplished like Pd (3.2.2.2.3.5) such that TC represents an additional S/N loss. Virtual target TC results will be applied after PSP Node 2 processing has been completed.

3.2.2.2.4 Modeling

A set of radar operating curves shall [40] be developed for the real-time MTI Simulation which relates MTI Pd (3.2.2.2.3.5) and CEP (3.2.2.2.3.3) statistics as a fuction of target S/N. These curves will be developed primarily from non-real-time Joint STARS simulations and tempered by empirical results obtained through flight test conditions. This approach enables the real-time MTI simulation to emulate the statistical tendencies of the Joint STARS radar over the infinite set of possible scan conditions encountered in the real world. The radar operating curves will be developed under baseline conditions of clear weather (3.2.2.2.2.1), for a nominal sized target (3.2.2.2.3.2), from which S/N variations will be interpolated.

3.2.3 SAR Imagery Simulation

The SAR Imagery simulation shall [41] receive as input from the RPS Control function (3.2.1) the SAR beam dwell data and the stationary virtual targets received over the DIS network. The stationary virtual targets will be geometrically filtered, modeled according to Joint STARS SAR resolution capabilities and mixed with the virtual terrain features within the SAR features database. Requests for SAR or FTI service shall [42] be considered a virtual SAR/FTI request if the central reference point (CRP) defining the SAR/FTI AOI falls within the virtual area. FTI processing will be a thresholded version of SAR Imagery processing.

3.2.3.1 SAR Imagery Control

*** TBD pending LORAL contract status***

3.2.3.2 SAR Imagery Processing

*** TBD pending LORAL contract status***

3.2.4 Stand Alone Mode

The RPS shall [43] be capable of executing in a simulation only mode, referred to as the Stand Alone mode, such that the RPS functions in the same manner as during flight mode, but without live data inputs. This mode requires all Joint STARS PME except those contained in the radar sensor group

(RSG), Programmable Signal Processors (PSP), and the Navigation subsystem. The interfaces with the missing PME will be simulated in real-time as defined in the following subsections.

3.2.4.1 Radar Control Simulation

The radar AUX data containing sensor commands used by the radar during each CPI shall [44] be simulated based upon the commands given in the Primary Mode Control (PMC) message sent by the RDP for each radar beam dwell. All other messages normally sent to or from the Radar Control Unit (RCU) on the 1553 Radar Sensor Bus (RSB) will be modeled for nominal conditions without errors induced. Radar Sensor IQ outputs will not be modeled.

3.2.4.2 PSP Simulation

The PSP setup / acknowledge, node 1 and node 2 communication paths with the RDP on the PSP LAN shall [45] be modeled based on the RDP inputs. No live targets or discretes will be simulated, and a nominal clutter environment will be used. All other messages normally sent to or from the PSP on the PSP LAN will be modeled for nominal conditions without errors induced. Radar sensor IQ inputs will not be modeled.

3.2.4.3 Navigation Simulation

The navigation data normally produced by the Joint STARS FMP CPCI Relative Navigation function shall [46] be simulated by the RPS. The navigation data contains platform position, velocity and attitude data as a function of time, and is output at a 10 Hz rate. The Navigation simulation will support a racetrack, figure eight, random, or circular orbit based on the contents of a navigation simulation file provided upon initialization of the RPS.

4. Quality Assurance

The contractor will be responsible for maintaining the RPS software under a configuration management system comparable with that developed for Joint STARS. The contractor will be responsible for verification of the RPS requirements and for justifying the selected methods of verification. The contractor will formulate a separate verification and validation plan for the E-8C RPS. The methods of verification will be by inspection, analysis, demonstration, or test.

5. Definitions

Provided in this section is a summary of acronyms used in this report.

- AOI : Area of Interest
- ATWS : Advanced Tactical Work Station
- CEP : Circular Error Probable
- CPI : Coherent Processing Interval
- DIS : Distributed Interactive Simulation
- DISNIU : DIS Network Interface Unit
- ECEF : Earth Centered Earth Fixed
- ES PDU : Entity State Protocol Data Unit
- GPC : General Purpose Computer
- Joint STARS : Joint Surveillance Target Attack Radar System
- LAN : Local Area Network
- LAOI : Live AOI
- MTI : Moving Target Indicator
- PFA : Probability of False Alarm
- Pd : Probability of Detection
- PSP : Programmable Signal Processor
- RCU : Radar Control Unit
- RDO : Radar Data Operational
- RDP : Radar Data Processor
- RPS : Radar Processor Simulation
- RSB : Radar Sensor Bus
- RSG : Radar Sensor Group
- RSR : Radar Service Request
- S / N : Signal-to-Noise Ration
- SAR : Synthetic Aperture Radar
- TC : Target Classification
- TCS : Topocentric Coordinate System
- WAN : Wide Area Network
- WGS-84 : World Geographic System 1984

References

[1] 3.1. Hardware Requirements. Inspection. Under normal conditions, the RPS shall consist of two distinct architectures, one on the ground (3.1.3) interfacing with the DIS network, and one on-board the Joint STARS platform (3.1.4) performing the MTI and SAR Imagery simulations.

[2] 3.1. Hardware Requirements. Demonstration. These two architectures shall be connected by an RF Link (3.1.2) during flight mode and with a LAN while in the lab environment.

[3] 3.1.1. Joint STARS Configuration. Inspection. The RPS shall be developed for incorporation into the third aircraft configuration used for low rate initial production of the E-8C Joint STARS.

[4] 3.1.3. Down Link Architecture. Test. The down link architecture shall be capable of logging PDUs for future data analysis and test purposes.

[5] 3.1.4. Up Link Architecture. Inspection. The up link processes developed for the RPS shall be hosted in one or more of the Joint STARS general purpose computers (GPC) on board the platform.

[6] 3.2.1.1.1. Identify Live AOIs. Test. Within these LAOIs, only "live" targets detected by Joint STARS shall be reported.

[7] 3.2.1.1.1. Identify Live AOIs. Test. Outside of these LAOIs, only "virtual" targets supplied to the RPS shall be reported.

[8] 3.2.1.1.1. Identify Live AOIs. Demonstration. The RPS shall maintain up to four LAOIs.

[9] 3.2.1.1.1. Identify Live AOIs. Inspection. The set of LAOIs shall be provided by the customer as a file to be read in upon initialization of the RPS and cannot be modified during the JADS exercise.

[10] 3.2.1.1.2. Identify Hypso and Carto Database. Inspection. The hypsographic and cartographic databases defining the features of the Joint STARS primary region shall be replaced upon initialization of the RPS with a new set of databases incorporating the virtual features for the JADS mission.

[11] 3.2.1.2. Operator Controls. Test. The RPS operator shall be given modest control of simulation parameters through the use of flags and thresholds.

[12] 3.2.1.3. DIS Interface Control. Inspection. The RPS control function shall receive ES PDUs over the DIS network and maintain a database of those ES PDUs applicable to the Joint STARS mission.

[13] 3.2.1.3.1. DIS Network. Inspection. ES PDUs shall be managed in two separate architectures, one on the ground connected to the DIS network, referred to as DISNIU I, and a second on the platform connected to the Joint STARS OWS and/or PSP LAN, referred to as DISNIU II.

[14] 3.2.1.3.1. DIS Network. Inspection. DISNIU I shall use the TCP/IP UDP protocol for communication on the DIS network.

[15] 3.2.1.3.2. Receive Entity State PDUs. Inspection. The RPS shall be required to maintain at least 5000 virtual targets, with a growth capacity of at least 20000 virtual targets.

[16] 3.2.1.3.2. Receive Entity State PDUs. Test. Virtual targets shall be deleted by the RPS when the war-games simulation issues a Remove Entity PDU or if "deactivated" by an ES PDU.

[17] 3.2.1.3.3. Coordinate Conversion. Inspection. ES PDU position and velocity shall be converted from ECEF to the Joint STARS Topocentric Coordinate System (TCS) by DISNIU I in order to save processor load for the Real-time MTI (3.2.2) and SAR Imagery (3.2.3) simulations on the platform.

[18] 3.2.1.3.3. Coordinate Conversion. Inspection. ES PDU orientation shall be converted from the entity coordinate system to TCS by DISNIU I.

[19] 3.2.1.3.4. Filter Entity State PDUs. Analysis. ES PDU information applicable to the MTI and SAR Imagery simulations shall be reduced to the minimum amount of information required by the real-time simulations in order to minimize the use of the available RF Link bandwidth.

[20] 3.2.1.3.4. Filter Entity State PDUs. Test. ES PDU filtering shall be performed on a maximum sustained rate of 100 virtual target updates per second plus the heartbeat rate.

[21] 3.2.1.3.5. Dead Reckoning. Inspection. Virtual targets received by DISNIU II shall be extrapolated to current time at a minimum rate of 5 Hz using a first order position update ($P = P_0 + V\Delta T$).

[22] 3.2.1.3.6. Joint STARS Entity State PDU. Test. The Joint STARS state message shall be sent at a 1 Hz rate by DISNIU II and output over the DIS network by DISNIU I when the dead reckoned platform position varies by more than the operator specified Joint STARS position threshold, or its heartbeat timer has expired.

[23] 3.2.2. MTI Simulation. Test. The virtual targets shall be geometrically filtered, have MTI statistics applied, and mixed with the appropriate live targets for output from the radar subsystem.

[24] 3.2.2. MTI Simulation. Test. The processing required by the MTI simulation shall not degrade the radar timeline beyond the nominal timeline fluctuations experienced by the Joint STARS radar under heavy target load conditions.

[25] 3.2.2.1. MIT Control. Inspection. The MTI control function shall determine those virtual targets within the current beam dwell footprint but not within the LAOIs.

[26] 3.2.2.1.3. Filter Live Targets. Test. Only those live targets which reside inside a LAOI shall be considered "detected" by the RPS.

[27] 3.2.2.1.4. Filter Virtual Targets. Test. Only those virtual targets which reside outside the LAOIs (aka virtual area) and within the current radar beam dwell footprint shall be considered for possible "detection" by the RPS.

[28] 3.2.2.1.5. Mix Live and Virtual Targets. Demonstration. For each radar beam dwell, the detected live moving targets (3.2.2.1.3) and the detected virtual moving targets (3.2.2.2) shall be merged into a single dwell report representing a mix of live and virtual targets within the same beam, but not overlapping in physical space.

[29] 3.2.2.2. MTI Processing. Demonstration. After the MTI control function (3.2.2.1) filters the virtual targets based on beam dwell and LAOI geometry, this simulation shall create a subset of these virtual targets which exhibit similar characteristics as live Joint STARS targets would under the same scan conditions.

[30] 3.2.2.2.2.1. Weather. Inspection. Weather conditions shall be assumed to be one of three categories; (1) clear; (2) cloud; (3) rain; as defined in the Joint STARS System Specification, as selected by the JADS operator (3.2.1.2).

[31] 3.2.2.2.2.2. Refraction. Inspection. The method employed by Joint STARS to determine the range refraction correction shall be used by the RPS to enhance symmetry between live an virtual targets.

[32] 3.2.2.2.2.3 Terrain. Test. The RPS shall identify those virtual targets obscured by terrain based on the hypsographic database, and the current platform position along the radar beam's line of sight.

[33] 3.2.2.2.3. Virtual Target Statistics. Inspection. MTI statistics shall be applied stochastically to the virtual targets using a uniformly distributed random number sequence in order to effectively simulate virtual targets as Joint STARS targets.

[34] 3.2.2.2.3.3. Location Accuracy. Test. Once the down range and cross range error has been established, these values shall be applied to the position vector (P_t) of the target.

[35] 3.2.2.2.3.5. Probability of Detection (Pd). Analysis. Radar operating curves (3.2.2.2.4) shall be developed off line which relate the radar beam dwell time to the Joint STARS azimuth (figure 3.2-3) and range (figure 3.2-4) constraints for a family of Pd and S / N levels.

[36] 3.2.2.2.3.5. Probability of Detection (Pd). Analysis. The RPS shall have a Pd versus radial velocity curve (figure 3.2-5) for each waveform identifier developed off line as per section (3.2.2.2.4).

[37] 3.2.2.2.3.5. Probability of Detection (Pd). Test. As a minimum, virtual target Pd (Pd_t) shall be derived from the following information; Scan conditions (3.2.2.2.1), Environmental factors (3.2.2.2.2), Virtual target geometry (3.2.2.2.3.1), and Target resolution (3.2.2.2.3.4).

[38] 3.2.2.2.3.6. Probability of False Alarm (PFA). Test) RSR receiver threshold levels shall be considered to increase or decrease the nominal PFA required by the Joint STARS System Specifications.

[39] 3.2.2.2.3.7. Target Classification (TC). Analysis. Since the double doppler component is significantly smaller than the actual target, determination of virtual target TC shall be accomplished like Pd (3.2.2.2.3.5) such that TC represents and additional S / N loss.

[40] 3.2.2.2.4. Modeling. Analysis. A set of radar operating curves shall be developed for the real-time MTI Simulation which relates MTI Pd (3.2.2.2.3.5) and CEP (3.2.2.2.3.3) statistics as a function of target S / N.

[41] 3.2.3. Sar Imagery Simulation. Demonstration. The SAR Imagery simulation shall receive as input from the RPS Control function (3.2.1) the SAR beam dwell data and the stationary virtual targets received over the DIS network.

[42] 3.2.3. SAR Imagery Simulation. Test. Requests for SAR or FTI service shall be considered a virtual SAR / FTI request if the central reference point (CRP) defining the SAR / FTI AOI falls within the virtual area.

[43] 3.2.4. Stand Alone Mode. Demonstration. The RPS shall be capable of executing in a simulation only mode, referred to as the Stand Alone mode, such that the RPS functions in the same manner as during flight mode, but without live data inputs.

[44] 3.2.4.1. Radar Control Simulation. Demonstration. The radar AUX data containing sensor commands used by the radar during each CPI shall be simulated based upon the commands given in the Primary Mode Control (PMC) message sent by the RDP for each radar beam dwell.

[45] 3.2.4.2. PSP Simulation. Demonstration. The PSP setup / acknowledge, node 1, and node 2 communication paths with the RDP on the PSP LAN shall be modeled based on the RDP inputs.

[46] 3.2.4.3. Navigation Simulation. Demonstration. The navigation data normally produced by the Joint STARS FMP CPCI Relative Navigation function shall be simulated by the RPS.

PRELIMINARY
Verification Cross Reference Matrix (VCRM)

Item	Paragraph	Paragraph Title	Method	Requirement
1	3.1	Hardware Requirements	Inspection	Under normal conditions, the RPS shall consist of two distinct architectures, one on the ground (3.1.3) interfacing with the DIS network, and one on-board the Joint STARS platform (3.1.4) performing the MTI and SAR Imagery simulations.
2	3.1	Hardware Requirements	Demonstration	These two architectures shall be connected by an RF Link (3.1.2) during flight mode and with a LAN while in the lab environment.
3	3.1.1	Joint STARS Configuration	Inspection	The RPS shall be developed for incorporation into the third aircraft configuration used for low rate initial production of the E-8C Joint STARS.
4	3.1.3	Down Link Architecture	Test	The down link architecture shall be capable of logging PDUs for future data analysis and test purposes.
5	3.1.4	Up Link Architecture	Inspection	The up link processes developed for the RPS shall be hosted in one or more of the Joint STARS general purpose computers (GPC) on board the platform.
6	3.2.1.1.1	Identify Live AOIs	Test	Within these LAOIs, only "live" targets detected by Joint STARS shall be reported.
7	3.2.1.1.1	Identify Live AOIs	Test	Outside of these LAOIs, only "virtual" targets supplied to the RPS shall be reported.
8	3.2.1.1.1	Identify Live AOIs	Demonstration	The RPS shall maintain up to four LAOIs.
9	3.2.1.1.1	Identify Live AOIs	Inspection	The set of LAOIs shall be provided by the customer as a file to be read in upon initialization of the RPS and cannot be modified during the JADS exercise.
10	3.2.1.1.2	Identify Hypso and Carto Database	Inspection	The hypsographic and cartographic databases defining the features of the Joint STARS primary region shall be replaced upon initialization of the RPS with a new set of databases incorporating the virtual features for the JADS mission.
11	3.2.1.2	Operator Controls	Test	The RPS operator shall be given modest control of simulation parameters through the use of flags and thresholds.

Item	Paragraph	Paragraph Title	Method	Requirement
12	3.2.1.3	DIS Interface Control	Inspection	The RPS control function shall receive ES PDUs over the DIS network and maintain a database of those ES PDUs applicable to the Joint STARS mission.
13	3.2.1.3.1	DIS Network	Inspection	ES PDUs shall be managed in two separate architectures, one on the ground connected to the DIS network, referred to as DISNIU I, and a second on the platform connected to the Joint STARS OWS and/or PSP LAN, referred to as DISNIU II.
14	3.2.1.3.1	DIS Network	Inspection	DISNIU I shall use the TCP/IP UDP protocol for communication on the DIS network.
15	3.2.1.3.2	Receive Entity State PDUs	Inspection	The RPS shall be required to maintain at least 5000 virtual targets, with a growth capacity of at least 20000 virtual targets.
16	3.2.1.3.2	Receive Entity State PDUs	Test	Virtual targets shall be deleted by the RPS when the war-games simulation issues a Remove Entity PDU or if "deactivated" by an ES PDU.
17	3.2.1.3.3	Coordinate Conversion	Inspection	ES PDU position and velocity shall be converted from ECEF to the Joint STARS Topocentric Coordinate System (TCS) by DISNIU I in order to save processor load for the Real-time MTI (3.2.2) and SAR Imagery (3.2.3) simulations on the platform.
18	3.2.1.3.3	Coordinate Conversion	Inspection	ES PDU orientation shall be converted from the entity coordinate system to TCS by DISNIU I.
19	3.2.1.3.4	Filter Entity State PDUs	Analysis	ES PDU information applicable to the MTI and SAR Imagery simulations shall be reduced to the minimum amount of information required by the real-time simulations in order to minimize the use of the available RF Link bandwidth.

Item	Paragraph	Paragraph Title	Method	Requirement
20	3.2.1.3.4	Filter Entity State PDUs	Test	ES PDU filtering shall be performed on a maximum sustained rate of 100 virtual target updates per second plus the heartbeat rate.
21	3.2.1.3.5	Dead Reckoning	Inspection	Virtual targets received by DISNIU II shall be extrapolated to current time at a minimum rate of 5 Hz using a first order position update ($P = P_0 + V\Delta T$).
22	3.2.1.3.6	Joint STARS Entity State PDU	Test	The Joint STARS state message shall be sent at a 1 Hz rate by DISNIU II and output over the DIS network by DISNIU I when the dead reckoned platform position varies by more than the operator specified Joint STARS position threshold, or its heartbeat timer has expired.
23	3.2.2	MTI Simulation	Test	The virtual targets shall be geometrically filtered, have MTI statistics applied, and mixed with the appropriate live targets for output from the radar subsystem.
24	3.2.2	MTI Simulation	Test	The processing required by the MTI simulation shall not degrade the radar timeline beyond the nominal timeline fluctuations experienced by the Joint STARS radar under heavy target load conditions.
25	3.2.2.1	MTI Control	Inspection	The MTI control function shall determine those virtual targets within the current beam dwell footprint but not within the LAOIs.
26	3.2.2.1.3	Filter Live Targets	Test	Only those live targets which reside inside a LAOI shall be considered "detected" by the RPS.
27	3.2.2.1.4	Filter Virtual Targets	Test	Only those virtual targets which reside outside the LAOIs (aka virtual area) and within the current radar beam dwell footprint shall be considered for possible "detection" by the RPS.
28	3.2.2.1.5	Mix Live and Virtual Targets	Demonstration	For each radar beam dwell, the detected live moving targets (3.2.2.1.3) and the detected virtual moving targets (3.2.2.2) shall be merged into a single dwell report representing a mix of live and virtual targets within the same beam, but not overlapping in physical space.
29	3.2.2.2	MTI Processing	Demonstration	After the MTI control function (3.2.2.1) filters the virtual targets based on beam dwell and LAOI geometry, this simulation shall create a subset of these virtual targets which exhibit similar characteristics as live Joint STARS targets would under the same scan conditions.

Item	Paragraph	Paragraph Title	Method	Requirement
30	3.2.2.2.2.1	Weather	Inspection	Weather conditions shall be assumed to be one of three categories; (1) clear; (2) cloud; (3) rain; as defined in the Joint STARS System Specification, as selected by the JADS operator (3.2.1.2).
31	3.2.2.2.2.2	Refraction	Inspection	The method employed by Joint STARS to determine the range refraction correction shall be used by the RPS to enhance symmetry between live an virtual targets.
32	3.2.2.2.2.3	Terrain	Test	The RPS shall identify those virtual targets obscured by terrain based on the hypsographic database, and the current platform position along the radar beam's line of sight.
33	3.2.2.2.3	Virtual Target Statistics	Inspection	MTI statistics shall be applied stochastically to the virtual targets using a uniformly distributed random number sequence in order to effectively simulate virtual targets as Joint STARS targets.
34	3.2.2.2.3.3	Location Accuracy	Test	Once the down range and cross range error has been established, these values shall be applied to the position vector (P_t) of the target.
35	3.2.2.2.3.5	Probability of Detection (Pd)	Analysis	Radar operating curves (3.2.2.2.4) shall be developed off line which relate the radar beam dwell time to the Joint STARS azimuth (figure 3.2-3) and range (figure 3.2-4) constraints for a family of Pd and S/N levels.
36	3.2.2.2.3.5	Probability of Detection (Pd)	Analysis	The RPS shall have a Pd versus radial velocity curve (figure 3.2-5) for each waveform identifier developed off line as per section (3.2.2.2.4).
37	3.2.2.2.3.5	Probability of Detection (Pd)	Test	As a minimum, virtual target Pd (Pd_t) shall be derived from the following information; Scan conditions (3.2.2.2.1), Environmental factors (3.2.2.2.2), Virtual target geometry (3.2.2.2.3.1), and Target resolution (3.2.2.2.3.4).
38	3.2.2.2.3.6	Probability of False Alarm (PFA)	Test	RSR receiver threshold levels shall be considered to increase or decrease the nominal PFA required by the Joint STARS System Specifications.
39	3.2.2.2.3.7	Target Classification (TC)	Analysis	Since the double doppler component is significantly smaller than the actual target, determination of virtual target TC shall be accomplished like Pd (3.2.2.2.3.5) such that TC represents and additional S / N loss.
40	3.2.2.2.4	Modeling	Analysis	A set of radar operating curves shall be developed for the real-time MTI Simulation which relates MTI Pd (3.2.2.2.3.5) and CEP (3.2.2.2.3.3) statistics as a function of target S / N.

Item	Paragraph	Paragraph Title	Method	Requirement
41	3.2.3	SAR Imagery Simulation	Demonstration	The SAR Imagery simulation shall receive as input from the RPS Control function (3.2.1) the SAR beam dwell data and the stationary virtual targets received over the DIS network.
42	3.2.3	SAR Imagery Simulation	Test	Requests for SAR or FTI service shall be considered a virtual SAR / FTI request if the central reference point (CRP) defining the SAR / FTI AOI falls within the virtual area.
43	3.2.4	Stand Alone Mode	Demonstration	The RPS shall be capable of executing in a simulation only mode, referred to as the Stand Alone mode, such that the RPS functions in the same manner as during flight mode, but without live data inputs.
44	3.2.4.1	Radar Control Simulation	Demonstration	The radar AUX data containing sensor commands used by the radar during each CPI shall be simulated based upon the commands given in the Primary Mode Control (PMC) message sent by the RDP for each radar beam dwell.
45	3.2.4.2	PSP Simulation	Demonstration	The PSP setup / acknowledge, node 1, and node 2 communication paths with the RDP on the PSP LAN shall be modeled based on the RDP inputs.
46	3.2.4.3	Navigation Simulation	Demonstration	The navigation data normally produced by the Joint STARS FMP CPCI Relative Navigation function shall be simulated by the RPS.

APPENDIX C

Modification of the

Entity State PDU

for

Use in the

End-to-End Test

Modification of the Entity State PDU for Use in the End-to-End Test

MAJ Terry Schmidt, U.S. Army
schmidt@jads.kirtland.af.mil
(505) 846-1015
Gary Marchand, SAIC
marchand@jads.kirtland.af.mil
(505) 845-1165
JADS JTF
11104 Menaul NE
Albuquerque, NM 87112

ABSTRACT

The End-To-End Test (ETE) is being conducted under the auspices of the Department of Defense Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E). The purpose of the ETE is to investigate the utility of using advanced distributed simulation (ADS) to augment both developmental and operational testing of the Joint STARS surveillance system. The basic concept behind the ETE is to augment the Joint STARS environment with a virtual environment created by thousands of simulated entities, or targets. This virtual environment is imaged by simulations of the radar systems contained within the Joint STARS E-8C aircraft and mixed with real radar returns to provide a robust operational environment for testing of the system.

The ETE Joint STARS simulation is called the Virtual Surveillance Target Attack Radar System (VSTARS). Simulated entities are transmitted to VSTARS through the use of Entity State Protocol Data Units (ESPDU). The simulation, or simulations, representing these entities transmit ESPDUs representing the status of each entity. This status is used to update data bases that are used to generate Joint STARS virtual radar images. Two modifications have been made to the ESPDU for use in the ETE. The first of these is a modification of the time field and is not mandatory, but is recommended. It records the time the ESPDU was created since the start of the simulation scenario. The second change to the ESPDU is performed internal to the Joint STARS simulation and is much more drastic. VSTARS must be capable of functioning anywhere needed, to include on board an aircraft during the conduct of a mission. This requires that the DIS network interface unit (NIU) for VSTARS exist in two parts, a ground NIU (GNIU) and an aircraft NIU (ANIU). The GNIU remains at a fixed location and receives ESPDUs from the DIS network. It then strips and modifies the ESPDU down to 192 bits of essential information and sends it to the ANIU. The ANIU performs the dead reckoning function and updates the data bases used to generate the virtual radar images. The ANIU resides in the same computer hosting VSTARS and may be found in a variety of locations such as a laboratory, on board the aircraft, or at a training site. This paper describes the modifications to the ESPDU and some of the reasons for the modifications. This procedure can be tailored for any sensor system that is not easily connected to a DIS network.

INTRODUCTION

The End-to-End Test (ETE) of the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) will evaluate the utility of using advanced distributed simulation (ADS) to complement the developmental and operational test and evaluation of a Command, Control, Communications, Computers, and Intelligence (C4I) system. The Joint STARS combination of E-8C aircraft and Ground Station was chosen as a representative C4I system on which to introduce ADS as a methodology in both DT&E and OT&E settings.

Joint STARS provides commanders access to near real-time radar imagery data in support of targeting decisions. The E-8C aircraft radar looks deep into hostile areas to detect, locate, classify, and track thousands of potential targets. This radar operates in two basic radar modes: moving target indicator (MTI) and synthetic aperture radar (SAR). MTI is capable of displaying the position of moving ground vehicles. SAR can provide images of both moving and nonmoving targets and of terrain and cultural features.

Previous C4I system testing has exhibited shortfalls in providing adequate numbers of forces, friendly or enemy, to realistically portray an expected operational environment. ADS can generate a robust test environment by providing a more representative number of threats, plus the complementary suite of other C4I and the weapons systems that interact with a C4I system. Through a seamless mixing of live and virtual targets, the ETE will add thousands of additional entities to the few hundred available in peacetime battlefield exercises, and will better replicate a developed theater.

The ETE is a four-phase test. Phases 1 and 2 occur in a laboratory environment, suitable for exploring DT&E and early OT&E applications. Phase 3 checks compatibility of the ADS environment with the actual Joint STARS equipment. Phase 4 is an ADS-enhanced live open-air test linking a flying E-8C aircraft to actual ground station receivers, intelligence systems, fire control, and virtual shooters. A schematic of Phase 4 is shown below.

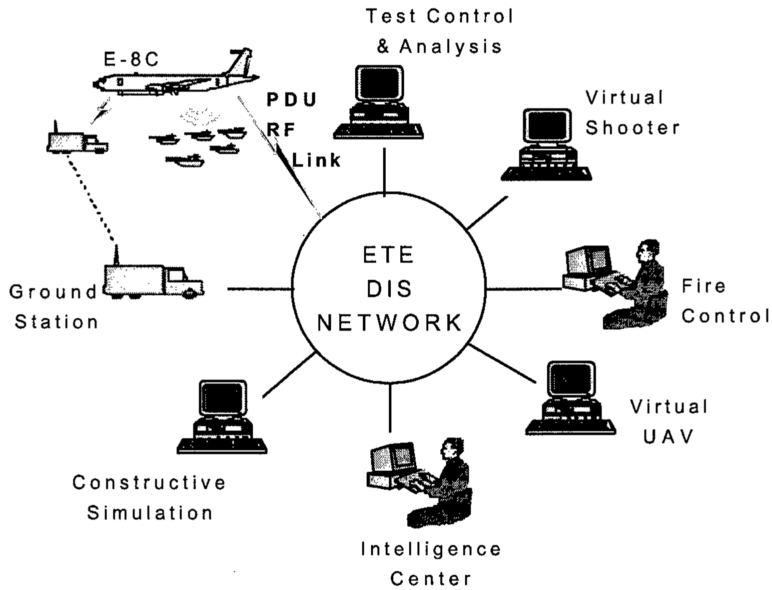

Figure 1. ETE Architecture

RF LIMITATIONS

In a typical DIS network, all simulation components are linked over local or wide-area ground-based networks. The ETE will link such ground networks, but also must include a flying aircraft receiving update information from a DIS network. This presents special challenges due to constraints on available radio frequency (RF) bandwidth between a ground transmitter and a receiver on board the aircraft. Current RF bandwidth available for the ETE is limited to around 19.2 kbps.

The current ETE network interfaces support a maximum of 100 ESPDUs per second. The DIS version 2.0.4 ESPDU contains 1152 bits of information (minimum), requiring a transmission rate of (1152)(100) = 115 kbps, much greater than the available bandwidth. Additionally, the E-8C aircraft provides an ESPDU denoting its existence and flight information on a 1 Hz update. This bandwidth discrepancy drove development of the modified ESPDU and network interface units used in the ETE.

ETE ARCHITECTURE

The VSTARS architecture receives ESPDUs from a DIS network through a ground network interface unit (GNIU), and transmits a modified PDU via an RF datalink to the corresponding air network interface unit (ANIU) aboard the flying aircraft.

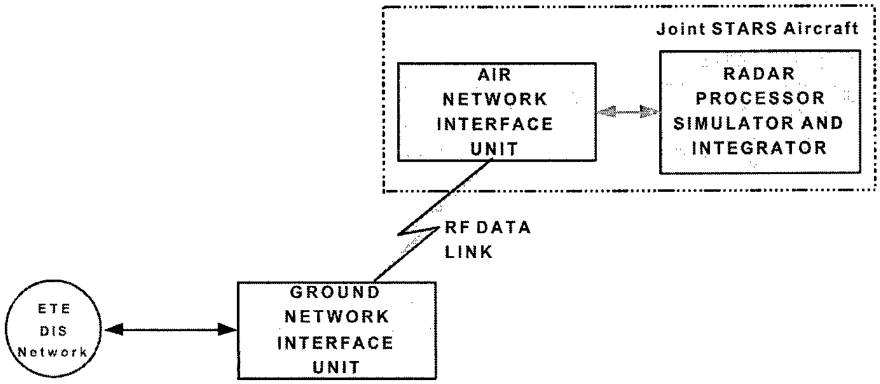

Figure 2: VSTARS Network Interface Units

NETWORK INTERFACE UNITS

The Ground Network Interface Unit first determines if arriving PDUs are Entity State PDUs. It then filters out those ESPDUs that are not within the E-8C simulation's area of interest. The remaining ESPDUs are stripped to a data packet containing the minimum information required to drive the MTI and SAR simulations in VSTARS. (This process is described later in this paper.) The GNIU converts location coordinates from DIS Earth-Centered-Earth-Fixed to the Topocentric Coordinate System used on-board the E-8C and in the RPSI. This conversion is done on the ground to save processing cycles onboard the aircraft. The GNIU then constructs an RF link message and transmits a stripped and modified data packet containing ground target information to the receiving ANIU.

The Air Network Interface Unit receives the incoming data packet and places the information in its target database. The ANIU performs dead reckoning on these targets, and updates the database based on its dead reckoning estimations and incoming target information. Dead reckoning is done on-board the aircraft to save RF transmission bandwidth from the GNIU. On request from the RPSI, the ANIU searches its database for those targets located in the appropriate ground location and provides such data to the RPSI SAR or MTI simulation.

Conversely, VSTARS provides to the ANIU data regarding the existence and location of the E-8C aircraft. The ANIU then composes and transmits a location data packet back to the GNIU denoting this information. The GNIU reforms the E-8C data into a DIS 2.0.4 ESPDU and broadcasts it to the DIS network.

ESPDU UPDATE MODIFICATIONS

DIS simulations normally send out ESPDUs on both a dead-reckoning update and a heartbeat basis. Dead-reckoning updates are sent whenever an entity location maintained in the simulation's internal location database exceeds by a given error parameter the locations maintained in some external DIS simulation database. Heartbeat ESPDUs are broadcast on a periodic basis (once every five seconds is recommended by the DIS standard) to permit simulations just entering the DIS network to initialize their databases, and also for those visual engines that require periodic updates.

The ETE simulation driver broadcasts dead-reckoning ESPDUs using the locational error parameters of the E-8C radar (i.e., radar CEP). This parameter can be decreased in the simulation software as necessary to account for latency in the ETE network. For example, assume the E-8C locational parameter error is 50 meters. A vehicle traveling at 5 meters / second can exceed the locational error in 5 seconds, necessitating an ESPDU update within 5 seconds. However, if network latency is 1 second, the dead-reckoning update must be shortened by at least 1 second (by adjustment of locational error parameter) for locational accuracy to remain within the aircraft radar CEP. Reducing the E-8C locational error parameter setting to 30 meters would require an ESPDU update in 3 seconds. On top of the 1 second latency, the updated ESPDU would arrive at a distant simulation in 4 seconds, which in effect is less than the radar CEP.

Between dead-reckoning updates, the ETE simulation driver broadcasts heartbeat ESPDU updates. Since the ETE network architecture and simulation participants are fixed prior to exercise initiation, no new players will join once the exercise begins; therefore, the newly entering simulation heartbeat requirement is eliminated. Also, none of the ETE visual engines require periodic updates. Were it not for the small chance of a non-mover being accidentally lost from the VSTARS database, this heartbeat could be eliminated. For VSTARS, the heartbeat is set initially and arbitrarily at a 10-minute update interval.

ETE ESPDUs arriving at VSTARS are maintained in a target database. Targets that are moving, or those stopping or starting, are updated as described above. Stationary targets are initialized in the database at exercise initiation. Once entered in the ANIU target database, targets are not routinely removed. Those targets that become battle-damaged or destroyed remain as burning hulks to be imaged by the E-8C SAR radar.

ESPDU DATA MODIFICATIONS

The VSTARS simulation driver need not provide the extensive target data available from the standard DIS ESPDU — information such as color, national origin, model, and so on is simply not visible to the E-8C radar sensor. This allows the ETE to strip such information from the ESPDU, and results in a smaller data packet that must be transmitted to the flying aircraft.

	Field Size ETE Modified ESPDU	
PDU Header	Time Stamp	32
Entity ID	Entity	16
Entity Type	Category	8
	Subcategory	8
	Specific	8
	Extra	8
Entity Linear Velocity	X-Component	16
	Y-Component	16
	Z-Component	16
Entity Location	X-Component	16
	Y-Component	16
	Z-Component	16
Entity Orientation	Psi	16
PDU Size		192 bits

Chart 1. ETE Modified ESPDU

- The VSTARS time stamp records the ESPDU creation time for up to 8 exercise hours, compared with the DIS protocol of restarting every hour. This is required by a normal 8 hour Joint STARS mission length.
- Entity Type contains the minimum information required for an overhead radar sensor as described above.
- Location data has been converted from Earth-Centered-Earth-Fixed to Topocentric Coordinate System and reduced to 16-bit accuracy, sufficient to remain within the error requirements of the E-8C radar.
- Likewise, velocity data has been reduced to 16-bit accuracy.
- Orientation is restricted to that visible to the E-8C radar in the radar slant plane.

Total Modified ESPDU size is 192 bits, compared with 1152 + 128n bits in the DIS 2.0.4 ESPDU.

		Field Size E-8C ESPDU
Header	Time stamp	32
E-8C Location	X-Component	32
	Y-Component	32
	Z-Component	32
E-8C Velocity	X-Component	32
	Y-Component	32
	Z-Component	32
TBD	reserved	32
Total PDU Size		256

Chart 2: ETE E-8C ESPDU composition

The E-8C aircraft transmits a 1 Hz state message from the ANIU to the GNIU denoting its existence, location, and velocity. The GNIU translates this into an E-8C ESPDU and broadcasts over the DIS network. This information permits the aircraft to be visible to other players in the DIS environment.

This results in the following transmission bandwidth requirements.

		entities / sec	# entities	# bits	kbps
Uplink Messages, GNIU to ANIU	Max sustained rate	100		19,200	19.2
	10 min heartbeat rate	33	20,000	6,400	6.4
Downlink Messages, ANIU to GNIU	Joint STARS state message @ 1hz	1	1	256	0.26
Total RF link bandwidth requirements					25.86

Chart 3: Transmission Bandwidth

Available ETE RF bandwidth to the ETE is 19.2 kbps. Using a nominal compression ratio of 1.4:1, the required bandwidth is reduced to 14 kbps, which fits within capacity.

CONCLUSIONS

For an overhead stand-off system such as MTI or SAR radar, the DIS ESPDU can be drastically reduced in size and still provide the resolution and fidelity necessary to provide accurate sensor information for training exercises or developmental and operational testing and evaluation. Such a procedure can be applied to any sensor that cannot 'see' all the detailed information available in the DIS ESPDU. The combination of ESPDU stripping and update rate modifications allows a flying aircraft to participate in a realistic DIS exercise. These procedures can be used to bring together various real combat equipment linked over radio nets into a DIS simulation without the restrictions posed by limited RF bandwidths.

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AUTHOR BIOGRAPHIES

TERRY A. SCHMIDT, Major, U.S. Army is the Team Lead for the End-to-End Test of the Joint Advanced Distributed Simulation Joint Test Force. He received a B.S. degree in Mechanical Engineering from Kansas State University, and an M.S. degree in Industrial Engineering and Mathematics from the University of Nebraska.

GARY J. MARCHAND, is the Technical Lead for the End-to-End Test of the Joint Advanced Distributed Simulation Joint Test Force. He received a B.S. degree from the United States Military Academy and an M.S. degree in Applied Science from the University of California Davis. He retired from the U.S. Army in 1993 as a Colonel after having been the Deputy Director, TRADOC Analysis Command, 1989-1993.

APPENDIX D

Joint Advanced Distributed Simulation

of

Joint STARS

Phase 1(B)

Final Scientific and Technical Report

JOINT ADVANCED DISTRIBUTED SIMULATION OF JOINT STARS

PHASE 1(B) FINAL SCIENTIFIC AND TECHNICAL REPORT

CONTRACT NO. F 30602-96-C-0281

Prepared for:

Department of the Air Force
Rome Laboratory/PKRZ
Rome NY 13441-4514

Prepared by:

Northrop Grumman
Surveillance and Battle Management Systems
Electronics & Systems Integration Division
200 W. NASA Boulevard, PO Box 9650
Melbourne, Florida 32902-9650

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1. Introduction

This document reports on the results of work conducted by Northrop Grumman to demonstrate the utility of existing Advanced Distributed Simulation (ADS) for use during Multi Service Operational Test and Evaluation (MOT&E). This project was sponsored by the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF). This white paper documents the Scientific and Technical accomplishments through Phase 1b of the program. This phase provided for a laboratory system development, demonstration, and preliminary performance assessment of a Radar Processor Simulation and Integrator (RPSI), for the purpose of simulating the Joint Surveillance Target and Attack Radar System (JSTARS) Radar products, with connections via the Distributed Interactive Simulation (DIS) network to the JADS End to End (ETE) simulated environment (SE).

ADS is defined as "any application or architecture which employs the characteristics of distribution and networking in a way which permits a number of nodes, entities, or devices (at least two) to interact with each other for some common or shared purpose related to Test and Evaluation (T&E), thus allowing the creation of realistic, complex, virtual worlds for the simulation of highly interactive activities." The three possible types of players (also known in the DIS community as participants or entities) are listed below:

- Live: real systems, real people, and real environments, operational platforms and test and evaluation systems.
- Virtual: simulators HIL/HWIL (Human in the Loop/ Hardware in the Loop)
- Constructive: models, digital simulations, computer generated forces, systems and environments and war games.

The term ADS has been developed to include network implementations which do not completely conform to the IEEE 1278 standards, but otherwise adhere to the basic tenets of DIS as described above. The term ADS includes DIS as a subset and is intended to support a mixture of virtual, live, and constructive entities. Northrop Grumman currently is contracted by the Joint Advanced Distributed Simulation Joint Test Force (JADS JTF) to develop a Joint STARS RPSI which interfaces to the DIS network. The DIS network is a media for participation in ADS activities.

2. Summary of the Project

The objective of this effort was to develop a system to enhance the existing JADS. JADS is being developed to prove the ADS concept by means of an ETE test scenario, whereby a battlefield environment is simulated including multiple moving and non moving targets, target detection, assignment, reporting, and target engagement. The Joint STARS E-8C platform is to be a major participant and will utilize the Joint STARS Radar and the RPSI to support the ETE Test that will be conducted by the

JADS JTF. The integrated E-8C Radar and simulation will provide simulated Radar reports integrated with live Radar reports when operating within the JADS JTF ETE Test environment.

Northrop Grumman was contracted to develop and implement a laboratory version of the RPSI and to provide the connections via the DIS to the JADS ETE simulated environment. Phase 1a consisted of an architecture and design study to determine the feasibility of the product. (See References 2, 3 and 4). The scope of the Phase 1b effort, which was based on that work included the design and development of VSTARS software compatible with JADS and the DIS network and standards. This software was integrated in commercial hardware with ancillary Radar control software tasks, i.e., those which normally are provided by the actual E-8C Prime Mission Equipment (PME). Some of the Joint STARS software was modified for use with the RPSI. VSTARS is the laboratory version of the RPSI, and is a simulation environment representing the generation and dissemination of Radar products by the Radar Subsystem of the E-8C aircraft.

Northrop Grumman has developed VSTARS consisting of a Distributed Interactive Simulation Interface Unit (DISNIU), a Radar Processor Simulator and Integrator (RPSI), and a Datalink Databus Interface Unit, to conclude Phase 1b. The RPSI is stimulated by virtual target data which are received in the form of Entity State Protocol Data Units (ES PDU) from the DIS network. These PDUs which are generated by a scenario generator, are data which describe the position, motion, orientation and identity of the virtual targets. The RPSI receives Radar Service Requests (RSR) from either an operator work station (OWS) or a Ground Station Module replica (GSMR) and provides Radar Target Reports (MTI and SAR) to the OWS and to the GSMR. In VSTARS, RPSI communication with the GSMR is provided by software tasks and a telephone link which simulate the Surveillance Control Data Link (SCDL) of the E-8C. The SAR simulation was developed by Lockheed Martin and was integrated into the RPSI by Northrop Grumman.

In addition, a preliminary performance assessment of VSTARS was successfully conducted, to ascertain that VSTARS satisfied the requirements and was ready for the planned follow-on phases of the JADS ETE program. This included characterization of the DIS interface by measuring the rate at which the entity state PDUs can be received.

The planned follow on JADS' phases are intended to verify and validate the results of this work, to migrate the RPSI to the Primary Mission Equipment (PME) of the E-8C aircraft, to conduct operational tests of the RPSI in a flying E-8C aircraft, and to support JADS ETE Team tests.

3. Task Description

The scope of this task included the design, development and test of software compatible with the existing JADS SE for the purpose of simulating the Joint STARS Radar effects on virtual targets.

The tasks which have been conducted during Phase 1b, were to develop a DIS Network Interface Unit (DISNIU), a RPSI and a Databus Datalink Interface Unit to satisfy the following requirements:

- Develop a DISNIU to receive, process and transmit DIS virtual target ES PDUs to the RPSI, and to transmit aircraft ES PDUs to the DIS network. Develop the DISNIU such that it can later be implemented in the E-8C PME.

- Develop a Joint STARS simulation consisting of a RPSI, which simulates the E-8C Joint STARS Radar Subsystem products and provides reports to OWS, and to remote ground stations, the latter via a specialized connection to a WAN. The RPSI architecture is in accordance with Architectural candidate 2, as described in reference 2, and satisfies the following requirements:

  - Provides for integration of simulated and live radar data when operating within the JADS Joint Test Force ETE environment.
  - Simulates the generation of MTI, SAR and Fixed Target Indicator (FTI) reports.
  - Operates in three modes: mixed, virtual and real.
  - Implements dead reckoning algorithms to minimize DIS network virtual target update requirements
  - Provides real or simulated aircraft inertial data information to the MTI and SAR simulations.
  - Is implemented within a commercial representation (ALPHA 600 Workstations) of the Joint STARS E-8C PME, in the Northrop Grumman ITF.

- Develop a Databus Datalink Interface Unit to enable the transmission SCDL traffic (MTI and SAR reports) to an Army GSM or CGS or replica of such; and to enable reception of Radar service requests from the ground station.

4. Technical Approach

The following paragraphs describe the work that was performed, the architecture selected, and the design of the RPSI. It also describes the associated interfaces between the JADS JTF facilities and the laboratory version of the RPSI, VSTARS. The RPSI software tasks are integrated with actual Radar subsystem software. Since the approach was to develop the RPSI to execute initially in the NG laboratory in ALPHA 600 work stations, and then in later phases to execute in the E-8C PME, existing Joint STARS subsystem software modules were integrated with the RPSI in the ALPHA 600 computers. These modules were augmented with additional software tasks, which were designed to intercept normal post processing outputs in order to insert simulated target information, and to provide the interfaces with the DIS network and the SCDL emulation. This provides for MTI and FTI reporting of the virtual targets and virtual SAR. During the planned follow on phases, only the newly developed and modified software will need to be migrated to the JSTARS PME, since the other Radar functions will be provided by existing, unmodified portions of the Radar subsystem.

4.1 RPSI Architecture and Design

The RPSI was developed to be in accordance with Architectural candidate 2, as described in Reference 2. Whereas the RPSI currently is implemented in commercial hardware in the laboratory, it was designed to enable the functional partitioning shown in Figure 4.1 when it is migrated to the E-8C PME. This figure shows the planned partitioning of the RPSI software to execute primarily in the "spare" general purpose computer (GPC-3), and in one of the Advanced Technology Workstations (ATWS). The following paragraphs describe VSTARS, the laboratory version of the Radar simulation.

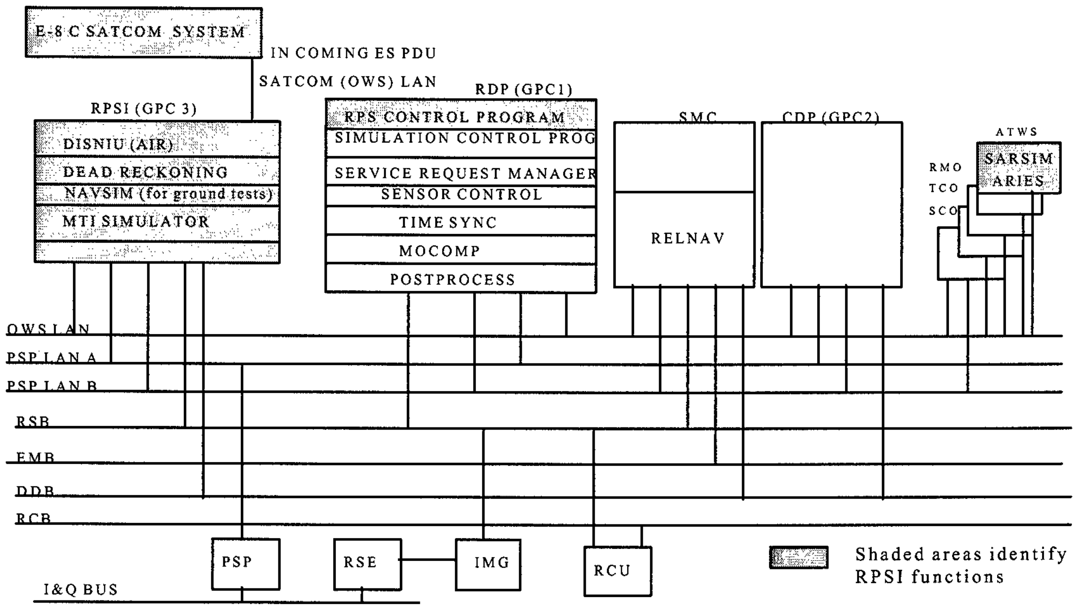


Figure 4. RPSI Functions to be Installed in JSTARS PME

4.2 VSTARS/RPSI Relationship to JSTARS

VSTARS was developed from a combination of existing Joint STARS Radar software and new software, and executes in two DEC ALPHA 600 workstations. It should be emphasized that the RPSI does not operate on its own but is integrated with actual Radar subsystem software.

VSTARS operates as follows:

Virtual target ES PDUs are received via a LAN and a T1 communication service, from the remote scenario generator, JANUS, via the DIS network. VSTARS DISNIU software receives and processes the PDUs, placing the virtual target data in global memory. The RPSI software accesses this data, simulates MTI and SAR processing affects and generates Radar Reports. These reports are provided via a LAN, for display at the OWS, or for transmission via a SCDL emulation to a remote GSMR, via a WAN (T1 communications service). The RPSI also receives Radar Service Requests from the GSMR via this WAN, and these are executed by VSTARS.

The combination of existing or modified Joint STARS Radar software and the newly developed RPSI software modules, which were migrated to the ALPHA 600 computers to perform these tasks are depicted in the following figures as unshaded and shaded blocks respectively. The "unshaded" functions provide for the auxiliary and parameter messages and controls, and reporting processes which normally are provided by the actual Radar Subsystem. Some of the "shaded" functions provide for the DISNIU functions, which receive and process the ES PDUs (bit stripping, coordinate conversion and dead reckoning which are described below). Other shaded functions provide for the SCDL emulation.

Additional shaded functions provide the simulation of MTI and SAR/FTI processing and product generation, and provide the interfaces between the RPSI and the Radar software tasks. Although the SATCOM Subsystem block is shown as shaded, the SATCOM processor software will be modified in the planned follow-on phases, to provide the RF link between the RPSI and the DIS network.

The result is a simulation of the Joint STARS Radar products "in a box" (the ALPHA 600 commercial computers), providing all of the JSTARS databases, post processing, operator displays and controls, and Operation and Control (O & C) Subsystem functions (e.g., target tracking and reporting) which are necessary for a realistic simulation of the Joint STARS Radar products generation and display and O & C Subsystem functions and interfaces.

Figure 4.2 provides a block diagram of the MTI processing mode and is an example of the relationship between the major Radar functions of the RPSI and of the Joint STARS RADAR software which comprise VSTARS. Figure 4.3 is the corresponding block diagram for the SAR processing mode of the RPSI. The operation of the RPSI Interfaces and the MTI and SAR simulation software tasks are described below in Paragraphs 4.2.3 and 4.2.4. But, first the RPSI laboratory hardware configuration and functional partitioning are described.

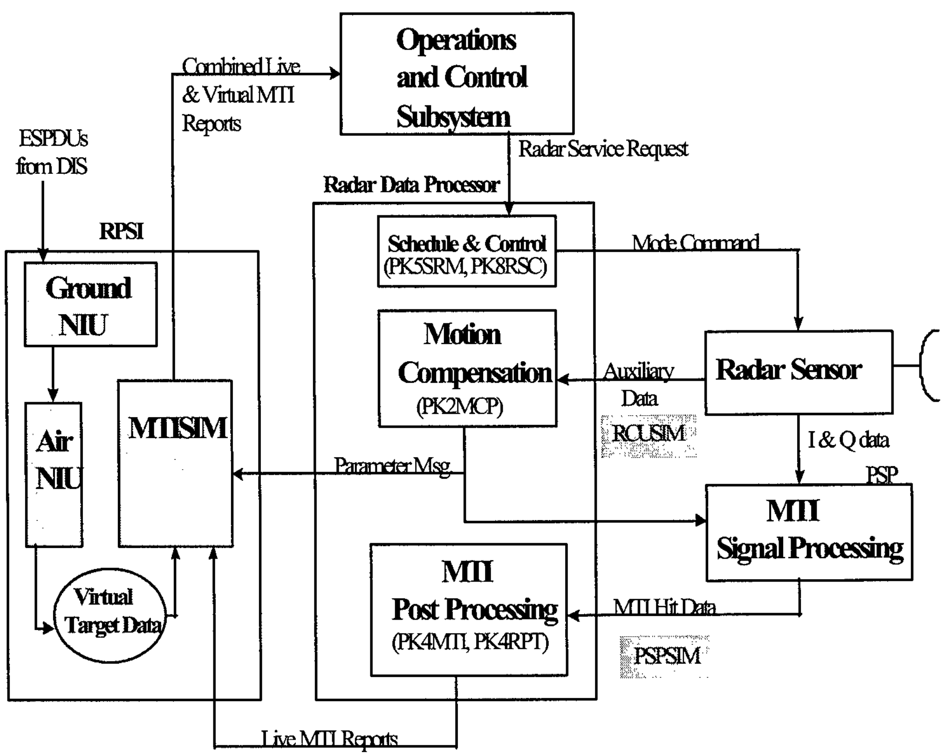


Figure 4.2 MTI Mode Shows Relationship & Dependency of the RPSI to the JSTARS RADAR

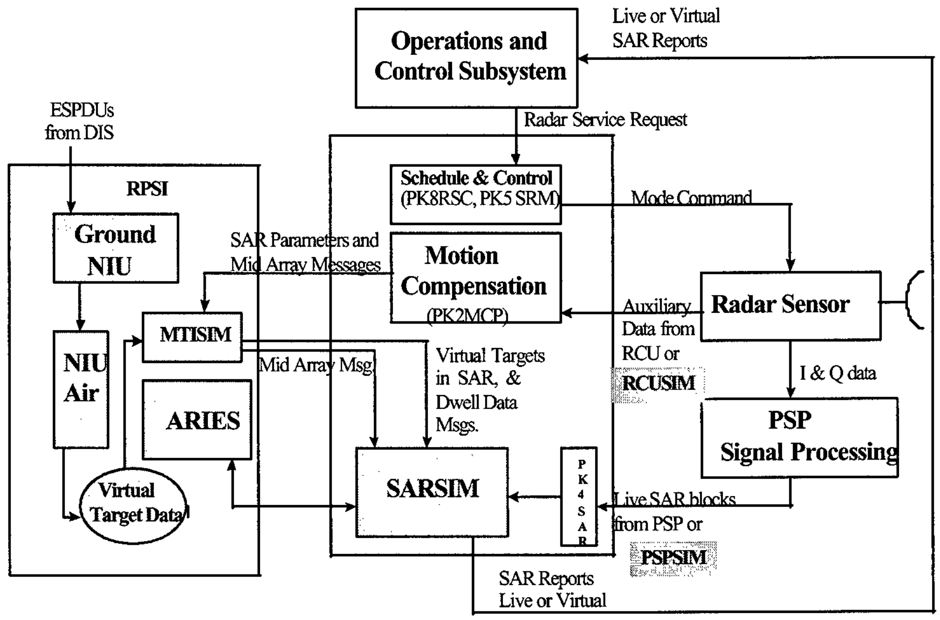


Figure 43 SAR Mode Block Diagram Shows Relationship & Dependency of RPSI TO JSTARS RADAR

4.2.1 Laboratory Hardware Configuration and Functional Partitioning

Figure 4.4 shows the laboratory configuration of the RPSI, known as VSTARS. VSTARS provides the software functions of the Joint STARS System Management and Control (SM&C) computer, the Radar Data Processor (RDP, known as GPC1), the Central Data Computer (CDP, known as GPC2) and the Advanced Technology Workstation (ATWS), by utilizing the actual Radar System software modules. As noted above, some of these were modified and additional software modules were developed for VSTARS.

At present all of VSTARS is configured to run on dual ALPHA 600 workstations with software functions partitioned as shown in Figure 4.4, or on a single ALPHA 600. SAR generation occurs more rapidly when two ALPHA 600s are utilized. Each ALPHA 600 is equipped with a single 333-Mhz

CPU. One is equipped with 512 MBytes of RAM, the other with 1 GByte of RAM for SAR processing. The operating system is DEC OpenVMS Version 7.0. The VSTARS software baseline is a variant of Joint STARS software Build 108B.

One of the workstations (JADS01) interfaces via an Ethernet LAN with an SGI workstation, which is used for logging or playback of the DIS PDUs. The SGI and the ALPHA 600 workstations connect via the LAN to a T-1 communication service network, which provides the interface to the DIS network. The interface which emulates the SCDL to the GSMR also is via a T1 communications service.

Both the DEC ALPHA 600 operator workstation keyboards and displays in the Northrop Grumman "JADS Laboratory", and the E-8C PME operator work stations (OWS) in the Northrop Grumman OCTL laboratory have been utilized with the RPSI executing in the ALPHA 600s. Since the latter OWS are the same as those utilized in the E-8C aircraft, they are utilized for realistic demonstrations of VSTARS and are recommended for realism when operator performance tests and assessment of VSTARS are to be conducted.

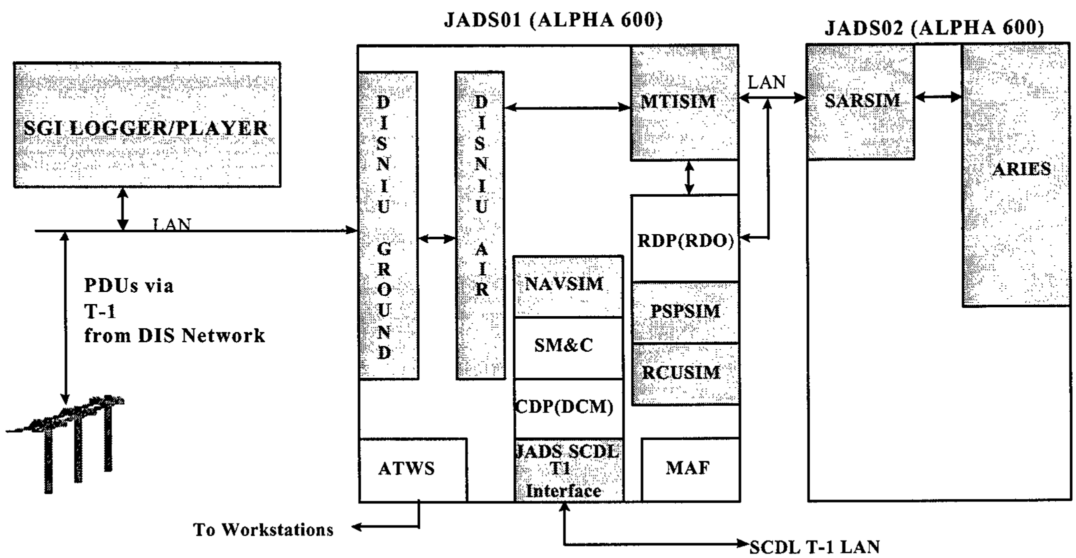


Figure 44 VSTARS, the Laboratory Configuration of the RPSI

4.2.2 DIS Interface Design and Operation

The DIS Interface provides for the receipt of ES PDUs from any DIS compliant PDU generator, (see Reference 6). For this project, PDUs were generated by JANUS and delivered via the T1 service and a Northrop Grumman Ethernet LAN directly to the DISNIU software tasks, or replayed from the SGI logger, which also records and can replay the PDUs that are received from JANUS. In order to provide for the eventual migration of the RPSI to an E-8C aircraft, the DISNIU software was designed with two parts: a Ground DISNIU (GNDNIU) and an Air DISNIU (AIRNIU). In VSTARS, the laboratory version of the JSTARS Radar emulation, both DISNIUs execute in an ALPHA 600. In the planned aircraft version, the AIRNIU will be installed in the aircraft PME. The GNDNIU will remain in the laboratory ALPHA 600 which will be interfaced with a ground site SATCOM system to provide an RF link to the aircraft (see section 4.2.7), and thence to the AIRNIU.

The GNDNIU software module (see JADS01 in Figure 4.4) interfaces with the Northrop Grumman Ethernet LAN which in turn interfaces with the DIS network via the T1 communication service. Although there are provisions for more than 1152 data bits in the standard DIS compliant PDU, this data was reduced to 192 bits in order to minimize the bandwidth requirements for passage of the target data to the aircraft. To achieve this compression, the PDUs received by the GNDNIU are stripped of the unnecessary data. The position and velocity data of the ESPDU are coordinate converted from an earth centered (geodetic) coordinate system to the Topocentric Coordinate System (TCS), which is employed by the JSTARS. The conversion algorithm utilizes the current Joint STARS mission center and supports the 512 by 512 km JSTARS mission area. The virtual target position is quantized to 16 meters and velocity is quantized to 0.0061 meters/second. The resultant 192 virtual target data bits (see Table 4.1) are forwarded to the AIRNIU.

This virtual target data is received from the GNDNIU by the AIRNIU and stored in global memory. Periodically, (currently once per second) the target position (of moving targets) is updated by dead reckoning. This data is available for further processing in the MTI or SAR processing mode, as described in the following sections.

The AIRNIU also has been designed to periodically (currently once per second) acquire and send an aircraft PDU to the GNDNIU, which in turn will deliver the aircraft PDU to the DIS network. Table 4.2 shows the PDU fields for this JSTARS downlink PDU. Although the RPSI simulates the generation and sending of aircraft PDUs, the software is designed so that the default mode for this function is "OFF", in order to eliminate any interference during the receipt of ES PDUs from the DIS network during laboratory tests.

Table 41 Uplink Entity State PDU for JADS RPSI

FIELD DATA	FORMAT	BITS IN FIELD	INFORMATION
Time Stamp	Unsigned Integer	32	
Local Target ID	Unsigned Short	16	Local Target ID No.
TCS X Cell	Unsigned Short	16	4K cell and 16m cell in Y axis
TCS Y Cell	Unsigned short	16	4K cell and 16 m cell in X axis
TCS Z Cell	Unsigned Short	16	(16383)m lsb=0.5m
Velocity X	Short	16	(200)m/s lsb=6.1035mm/sec
Velocity Y	Short	16	(200)m/s lsb=6.1035mm/sec
Velocity Z	Short	16	(200)m/s lsb=6.1035mm/sec
Entity Category	char	8	enumeration
Entity Sub Category	char	8	enumeration
Entity Specific	char	8	enumeration
Appearance	char	8	8 bit extraction from 32 bits
Orientation Angle	short	16	(180)deg. extraction from 32 bits
TOTAL BITS		192	

Table 42 Downlink Entity State PDU for JADS RPSI

FIELD DATA	FORMAT	BITS IN FIELD
Time Stamp	Unsigned Integer	32
TCS Location X	Float	32
TCS Location Y	Float	32
TCS Location Z	Float	32
TCS Velocity X	Float	32
TCS Velocity Y	Float	32
TCS Velocity Z	Float	32
TBD	Integer	32
TOTAL BITS		256

4.2.3 MTI Processing Simulation

The MTI simulation, which was designed for the laboratory version of the RPSI, is illustrated in Figure 4.5 which shows the major software tasks and message flow.

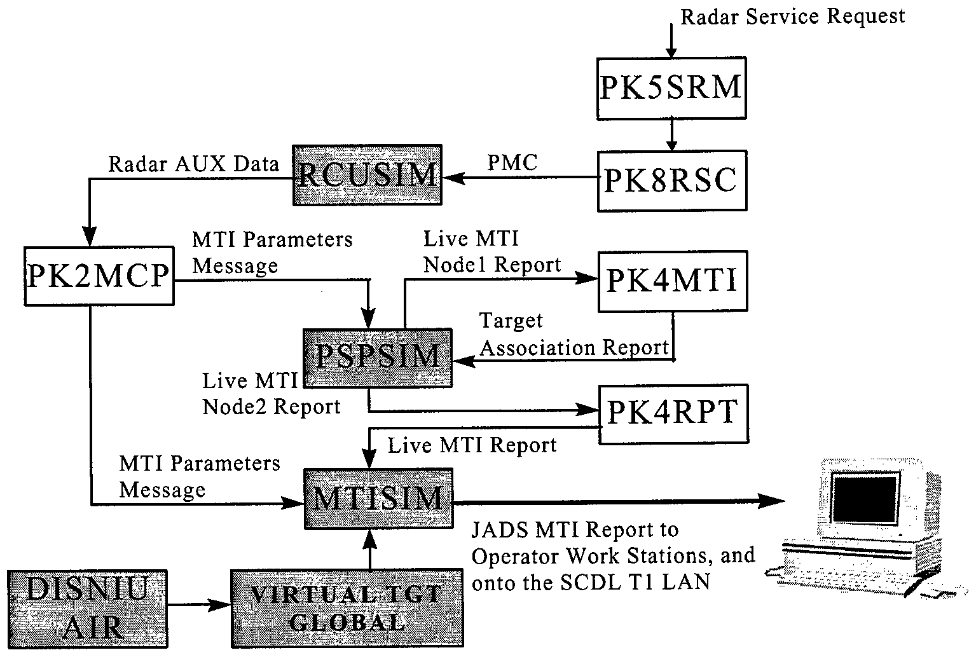


Figure 4.5 RPSI MTI Processing Simulation (Laboratory Mode)

RCUSIM and PSPSIM are software tasks which were developed for VSTARS, to be used in the laboratory version of the RPSI. These software modules provide for those inputs which normally are provided by the actual Radar Control Unit (RCU), and the Programmable Signal Processors (PSP) of the Radar system. These operate in conjunction with new RPSI software tasks.

MTISIM and the DISNIU software tasks and the modified PK2MCP, PK4RPT and PK5SRM software will form part of the RPSI software which will be migrated to the E-8C PME during follow on phases. PSPSIM and RCUSIM will not be required in the aircraft, since the functions which are provided by these software tasks in the laboratory will be provided in the aircraft by the Programmable Signal Processors (PSP) and the Radar Control Unit (RCU) of the JSTARS Radar subsystem.

The new RPSI software task, MTISIM, receives the virtual target data from global memory, and processes the virtual targets that fall within the MTI dwell. This task "detects" virtual targets based on target probability of detection (Pd), velocity, and terrain and generates a combined MTI report containing virtual and real targets (in mixed mode). MTISIM performs the following major operations:

- Processes the MTI parameters message and identifies the 4km by 4 km grids encompassed within an MTI dwell.
- Builds the MTI dwell data structure. (RSR ID, Number of Live AOI, PRIs, MTI resolution , etc.,)
- Determines if any 'Live" MTI targets must be loaded into the combined JADS MTI Target Report
- Determines if any Virtual MTI targets must be loaded into the combined JADS MTI Target Report
- Applies Probability of Detection (P_d) and Target Location Circular Error Probability (CEP) statistics (see Reference 4 and Section 0), and Terrain Screening tests for each of the Virtual targets located within those 4x4 km. grids which are within the Radar footprint.
- Issues the combined JADS MTI Target Report to the Operator Work Stations and to the SCDL interface.

The two most observable performance characteristics of target reports from the Radar are P_d and target location accuracy. The high fidelity P_d computation accounts for the various target to noise ratio losses and processing gains characterizing the Radar, the environmental conditions and the geometric relationship of the target to the Radar scan. The P_d calculation was fine tuned based on actual JSTARS System Level Performance Verification (SLPV) flight test data. (see Section 5). An analysis of controlled SLPV flight test data provided the best insight into the actual errors that were modeled for the JADS simulation.

An example of the comparison between SLPV flight test data and the JADS simulation is shown below in Figure 4.6 for twelve distinct SLPV Test Points. The chart shows that the JADS estimate of P_d was slightly more optimistic than the flight data (on average about 3-4%). This can easily be attributed to errors in the assumptions of target size and environmental conditions.

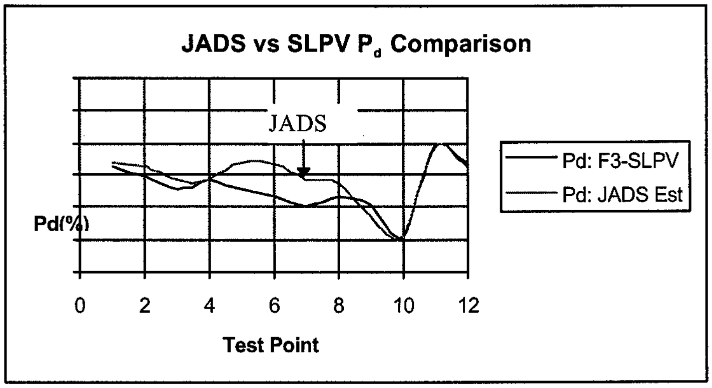
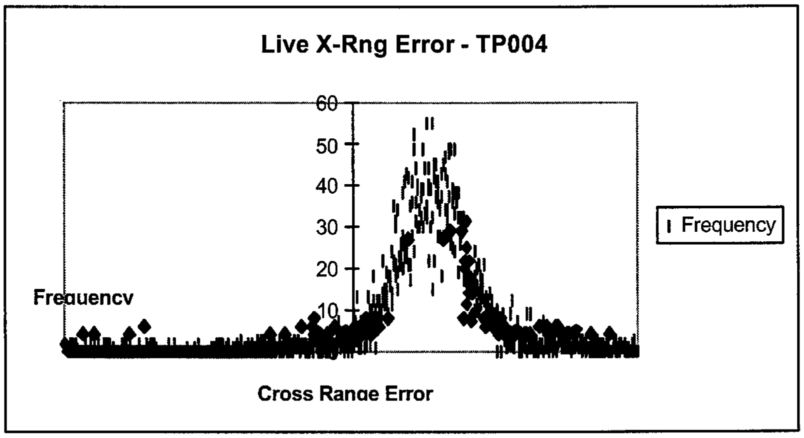


Figure 4.6 Comparison of P_d for JADS Simulation and SLPV Flight Test Data

MTI target location error statistics derived from the 1 sigma errors in range, cone angle, vertical separation and coordinates also were applied. These were derived from a two dimensional theoretical model and from SLPV flight data taken under controlled conditions. The down range, cross range and Circular Error Probability (CEP) statistics were utilized in the JADS CEP algorithms and applied to the JADS virtual targets based on their true range and angle to the aircraft.

Figure 4.7 below provides an example illustrating the close similarity in the frequency distributions of cross range error for the Live data that was derived from SLPV flight data, and the corresponding cross range error from the JADS simulation.



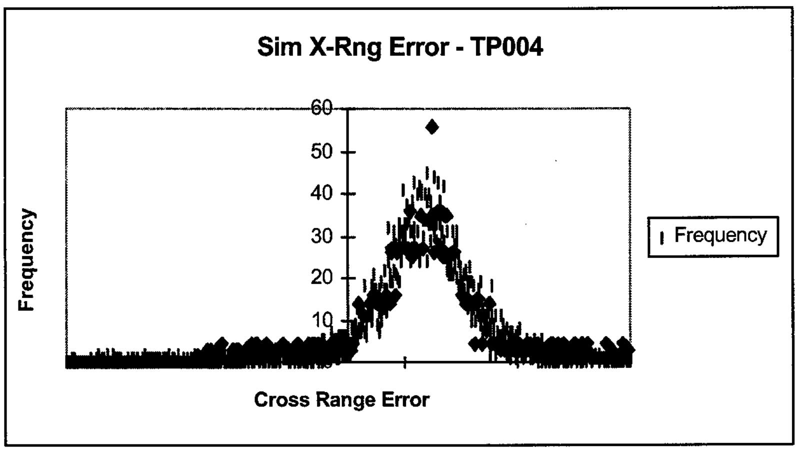


Figure 47 Cross range error distributions for Flight Test Data and JADS Simulation Data

Radial Velocity quality and error statistics also were derived from data collected under controlled conditions during SLPV flight tests. A more detailed description of all these analyses and results is presented in Section 5 of this report.

The MTI simulation software tasks operate as follows in the laboratory version: The JSTARS software task, PK8RSC (radar sensor control), commanded by receipt of a Radar Service Request (RSR), sends Primary Mode Control (PMC) messages to the VSTARS task, RCUSIM, which generates and sends Radar Auxiliary Data messages to the JSTARS Radar Data Processor (RDP) MOCOMP task, PK2MCP. The VSTARS task, PSPSIM receives MTI parameters message from PK2MCP and generates and forwards an MTI node 1 report with random radar hits representing live (noise in the laboratory version) MTI data to the JSTARS RDO task, PK4MTI, which provides a Target Association report to PSPSIM. PSPSIM then provides a Live MTI "node 2 report" to the JSTARS task, PK4RPT, from which after coordinate conversion (range-angle to TCS) and formatting, the Live MTI Report is sent to the RPSI task, MTISIM. MTISIM also receives the MTI parameters message from PK2MCP. MTISIM processes the virtual target data and issues the combined Live and Virtual MTI Target Report to the Operator Work Station for display.

4.2.4 SAR Processing Simulation

The SAR simulation which was designed for the laboratory version of the RPSI, is illustrated in Figure 4.8 which shows the major software tasks and message flow. When a SAR image is requested the RPSI generates realistic SAR images using a Lockheed Martin software product (Advanced Radar Imaging Emulation System, ARIES), which is integrated with the NG RPSI software.

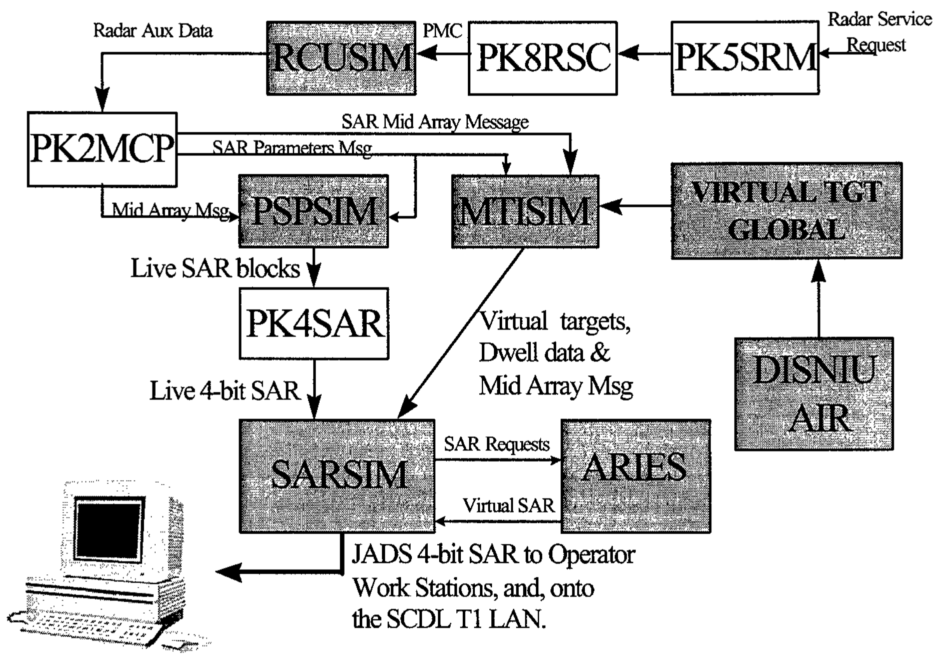


Figure 4.8 RPSI SAR Mode Processing Simulation (Laboratory Mode)

When a SAR image is requested, for a particular SAR area of interest (AOI), the new RPSI software task, SARSIM, receives the SAR Mid Array message from MTISIM, and if the SAR is in a "virtual area", sends a SAR Simulation Parameters message to ARIES software modules (see Reference 5). The SAR Simulation Parameters message contains the SAR image request and the operational and navigational data including the AOI, sensor parameters (resolution, wavelength, dwell time, coverage width, range extent, antenna orientation), platform state data, and target information. ARIES generates

the simulated SAR images from Digital Terrain Elevation and Feature data bases for the AOI. ARIES takes this data and SAR parameters and develops a point map for locating terrain features including elevation and targets in the image. It then uses this map to perform a 3-D to 2-D projection that simulates what would be seen in the actual Radar Subsystem.

A height parameter is used to generate obscuration, shadows and surface gain reflectivity, including edge reflectivity effects. Virtual targets, textures, and features are inserted into the image. Moving Targets are inserted last into the image. Image processing of this "raw" image blends edges, seams and boundaries. A simulated SAR Image Report that contains an image of the virtual area which was indicated in the SAR Simulations Parameters message, then is returned to SARSIM. SARSIM scan converts the SAR images from "range-doppler" coordinates to the X-Y pixel display format, and sends the images to the OWSs, and to the Operations and Control (OCO) CPCI when required for transmission via the SCDL.

The SAR simulation software tasks operate as follows: When the JSTARS task, PK8RSC (radar sensor control) receives the RSR for a SAR image, it sends primary mode control messages to the VSTARS task, RCUSIM, which generates and sends Radar Auxiliary Data messages to the JSTARS RDO MOCOMP task, PK2MCP. PK2MCP sends SAR parameters and mid-array messages to PSPSIM and to MTISIM. PSPSIM generates "Live" (fake data, derived from noise in the laboratory version) SAR data blocks. The RDO task PK4SAR, receives these multiple blocks and formats the "Live" SAR images. These images are then sent to the RPSI task, SARSIM. If the SAR has been requested for a "live" area this live SAR is forwarded to the OWS. Otherwise it is "dumped".

MTISIM loads dwell data, determines the virtual targets within the SAR Area of Interest (AOI), and determines whether the requested SAR is in a "Virtual" or a "Live" AOI. When the requested SAR is in a Virtual area MTISIM sends to the RPSI task, SARSIM, a new SAR parameters message containing the dwell data and mid array messages, and the virtual targets within the SAR AOI. When a SAR has been requested for a "virtual " area, SARSIM sends the SAR Simulation Parameters message to ARIES, and ARIES generates the simulated SAR as described above.

The ARIES and SARSIM software, and modified versions of PK2MCP, PK4SAR and PK5SRM will be migrated to the E-8C PME during JADS Phase 2. PK5SRM is the Radar Service Request Manager software task.

4.2.5 Navigation Simulation Processing

In the E-8C platform, navigation sensor information is provided to the Radar subsystem by the navigation sensors. The navigation simulation process which was designed for ground and laboratory usage of the RPSI is illustrated in Figure 4.9.

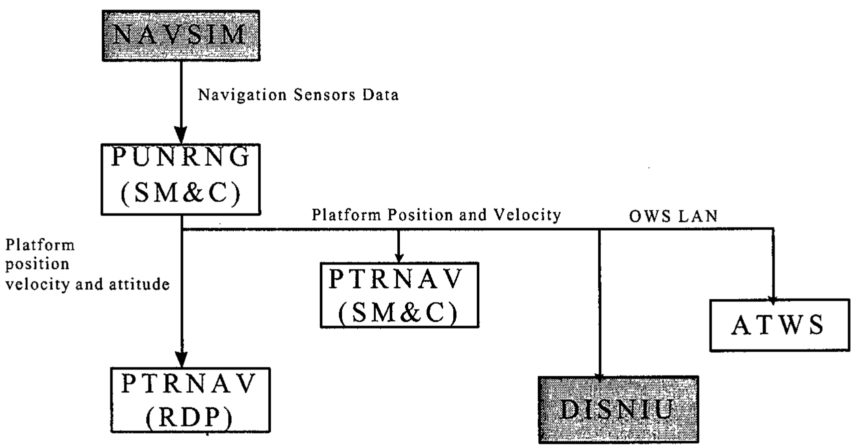


Figure 4.9 Navigation Simulation Processing

This process, NAVSIM, simulates the various navigation sensors (GPS, INUs, IMG and CADCs) of the E-8C aircraft and thereby provides the needed navigation information to the RPSI. NAVSIM also generates and provides simulated aircraft position and velocity (as an aircraft PDU) to the DISNIU. Although NAVSIM will not be required for the aircraft version of the RPSI when the aircraft is flying (since the actual navigation sensors will be employed), it is expected that for ground tests of the RPSI in the PME, NAVSIM will be utilized.

NAVSIM simulates and provides this navigation sensor data to the JSTARS software task, PUNRNG which normally executes in an SM & C computer of the E-8C PME. PUNRNG was modified for JADS and replicated in one of the ALPHA 600s (Figure 4.4). PUNRNG filters and merges the navigation sensors data and provides platform position, velocity and attitude data to the JSTARS task, PTRNAV for use in the RPSI MTI and SAR processing. PTRNAV normally executes in the SM&C and the RDP of the JSTARS PME, and was replicated in the ALPHA 600. Platform location data also are provided to the ATWS for display of the navigation data and a depiction of the orbiting aircraft. The platform position and velocity data also is made available for periodic (currently set at once per second) formatting and transmission of aircraft PDUs to the AIRNIU, for transmission to the GNDNIU and thence to the DIS network. (See Paragraph 4.2.2).

4.2.6 Data Link Interface Design (SCDL)

In the laboratory version of the RPSI, a Databus Datalink Interface Unit was developed to enable the transmission of Surveillance and Control Data Link (SCDL) traffic (e.g., MTI and SAR reports) to an Army ground station such as a Ground Station Module (GSM) or Common Ground Station (CGS), or replica (GSMR) of such, and to enable reception by VSTARS of Radar service requests (RSR) from the ground station.

In the E-8C aircraft SCDL traffic is accommodated by a 1553B data bus between the Central Data Processor (CDP) and the SCDL Air Data Terminal (ADT), which interfaces with the ground station via an RF link. See Figure 4.1. The Datalink Communications Management CPCI, (DCM) controls and monitors the equipment in the datalink subsystem and provides for bi-directional communications. DCM software normally executes in the Central Data Processor (CDP) and the OWSs of the Operations and Control (O&C) Subsystem. DCM interfaces to the SCDL ADT via the 1553 digital data bus (DDB) interface task, PTBDDB, and this allows the ADT to communicate with the JSTARS Radar and O&C subsystems.

For the laboratory version of the RPSI, the 1553B interface was bypassed and instead of the RF link, a LAN and T1 communications services were utilized as the communications media between VSTARS in the Northrop Grumman, Melbourne, Fl. laboratory, and the Motorola GSM replica in Phoenix, Az. During JADS Phase 2 this communication will be from NG to the GSMR which will be located at Fort Hood. The simulation of the SCDL interface and communication is illustrated in Figure 4.10.

Existing JSTARS CPCI, DCM, and task, PTBDDB, which provide for the SCDL communications in the E-8C platform, were modified and replicated in one of the ALPHA 600s. Two additional JADS software tasks (JDSRCV and JDSXMT) were designed to interface these functions and the T1 LAN.

The JADS SCDL interface operates as follows:

Modified SEM process, PTBDDB performs the following functions

- Determines if JADS SCDL T1 LAN interface software is executing.
- Stops all I/O which normally executes to the SCDL DDB 1553B card on the CDP, when JDSXMT and JDSRCV are executing.
- Reroutes SCDL Downlink messages (e.g. MTI and SAR reports) from the DCM CPCI to the JADS Transmit (JDSXMT) process.
- Forwards all SCDL Uplink messages from the JADS SCDL Receive process (JDSRCV) to the DCM CPCI process PW5SUM.
- Simulates SCDL ADT functions to satisfy JSTARS software that the SCDL ADT is operational

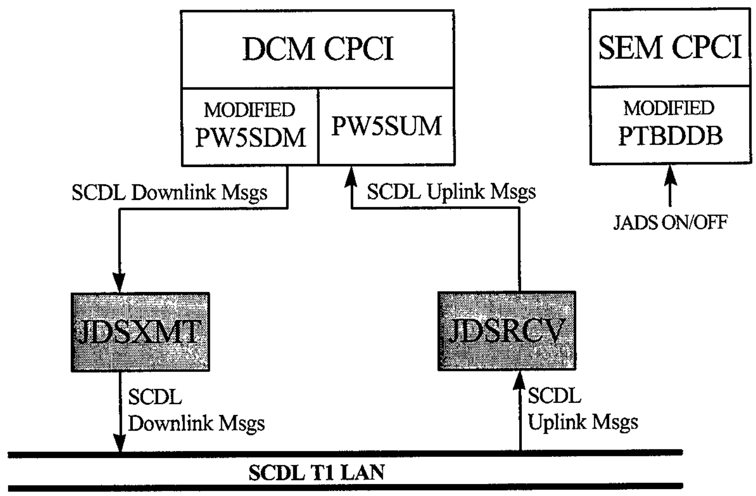


Figure 4.10 SCDL Simulation (Laboratory Mode Only)

The JADS SCDL software tasks perform the following functions:

- JADS SCDL TRANSMIT PROCESS JDSXMT:
    - Reads Initialization parameters to determine which User Datagram Protocol (UDP) port is used for transmission, and the Motorola GSMR SCDL ADT Internet Protocol (IP) address.
    - Notifies PTBDDB of JDSXMT execution status via message at process initialization and shutdown.
    - Transmits SCDL DDB messages from the PW5SDM process to the Motorola GSMR SCDL T1 LAN via UDP
    - Performs UDP socket cleanup and process shutdown

- JADS SCDL RECEIVE PROCESS JDSRCV:
    - Reads Initialization parameters to determine which UDP port is used for reception, and the Motorola GSMR SCDL ADT IP address.
    - Notifies PTBDDB of JDSRCV execution status via message at process initialization and shutdown.

    PW5SUM receives via UDP all SCDL T1 LAN messages from the Motorola GSMR SCDL Ground ADT simulator via the SCDL T1 LAN.

- Forwards all SCDL T1 LAN messages to the PTBDDB process for processing by the DCM CPCI.
- Performs UDP socket cleanup and process shutdown.

The JADS software tasks, JDSRCV and JDSXMT, will not be required in the aircraft. The functions which provide for SCDL data link in the aircraft already form a part of the JSTARS software.

4.2.7 Future RF Link Requirements, Design and Performance Prediction

In order for the RPSI DISNIU to be implemented in the future in the E-8C PME, an RF link must be established between the AIRNIU (See Paragraph 4.2.2) and the GRNDNIU. This link will provide for the transmittal of virtual target data (via entity state PDU) from a ground site (designated as the Northrop Grumman laboratory in Melbourne, FL) to an E-8C aircraft in flight, and for the transmittal of E-8C PDU from the aircraft to the ground site. In the follow on JADS/VSTARS work phases, Northrop Grumman will provide system and software support to develop this RF Link Interface.

During JADS Phase1b, Northrop Grumman supported the Government in running message load tests to establish the basic RF bandwidth requirements for the RF link design (see Reference 10). Other tests were conducted which confirmed the ability of the GRNDNIU to accommodate the receipt of PDUs at rates up to 1100 PDUs per second. This is greater than the bandwidth capabilities of a T1 communication service (estimated at approximately 350 PDUs/second). This rate also is much higher than the anticipated rate (estimated at less than 100 PDU per second), at which PDUs will be issued from DIS or to the aircraft. This was tested by replaying PDUs from the SGI logger at various rates and viewing on the OWS display a table indicating the count and receipt of PDUs by the GNIU.

In advance of the planned Phase 2 work, RF link studies also were conducted during the development of VSTARS, and resulted in the selection of the E-8C ("Contingency Enhancements") UHF SATCOM system and equivalent ground site SATCOM components as the recommended baseline hardware system and software for this link. This recommendation was driven by the following requirements:

- The link not be limited by line of sight considerations;
- The link should be implemented as much as possible with existing aircraft and ground site hardware and software.

Figure 4.11 illustrates the recommended concept of operation of the DISNIU RF link. Virtual target PDUs will be received from the DIS network by the Ground DISNIU in the Alpha 600, via the T1 communication service and an Ethernet LAN in the NG ITF. After processing (see Paragraph 4.2.2) in the GRNDNIU, the virtual target information will be passed to a ground station SATCOM system in the ITF, formatted, and transmitted via the SATCOM RF link to the E-8C aircraft. The airborne SATCOM subsystem will extract the virtual target data and pass it to the AIRNIU in the RPSI in the PME, where the data will be processed as described in Paragraph 0. E-8C ES PDUs will be formed in the RPSI and periodically forwarded to the ground site GNIU via the same SATCOM downlink.

RF LINK INTERFACE

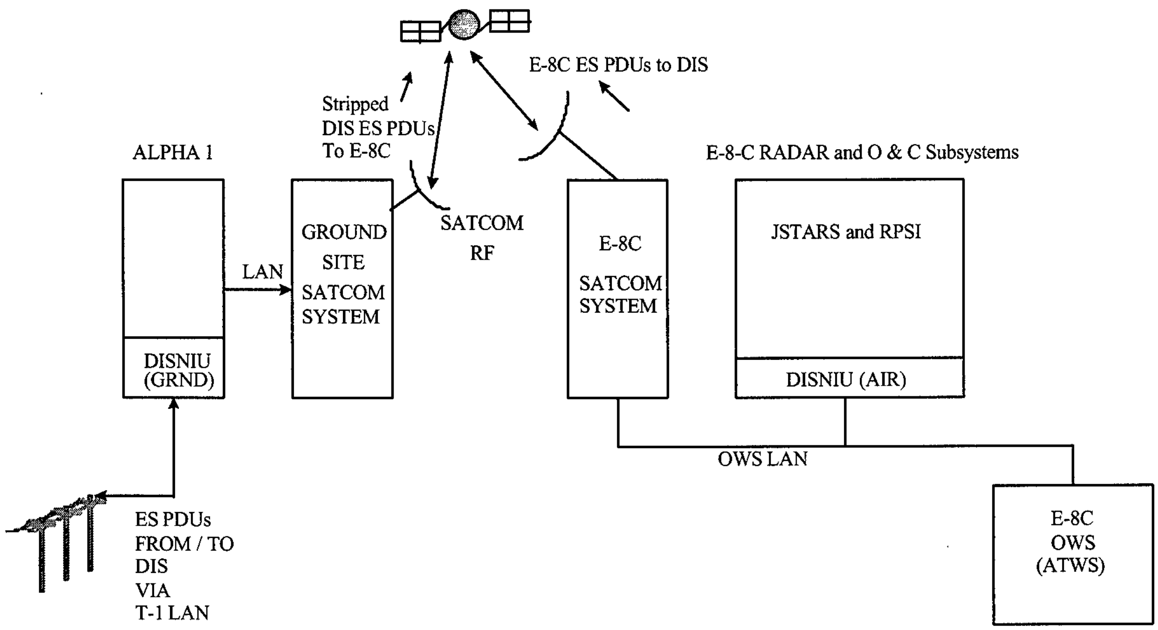


Figure 4.1 SATCOM Will Provide the RF Link Between the GNDNIU and the AIRNIU

4.2.8 E-8C SATCOM System Overview and Study Recommendations

Figure 4.12 shows the major functional components of the current E-8C "Contingency Enhancements" SATCOM hardware suite, as recommended for JADS. Other components in the SATCOM suite that are not required for JADS are not shown. The primary elements of the SATCOM subsystem include a UHF antenna, a Multi-mission UHF Satellite Transceiver, a Data Encryption Unit, a SATCOM Processor/Computer, an ALPHA workstation and an OWS LAN interface to the Joint STARS Radar System.

The E-8C SATCOM subsystem currently can provide a secure, over the horizon communication's link, to transmit navigation and RADAR MTI and SAR data from the aircraft to a ground station, as well as to transmit messages from a ground site to the aircraft. The aircraft utilizes two different SATCOM systems. It is intended to utilize one of these systems, with modified software to accommodate the JADS RPSI RF link requirements in the aircraft. An equivalent suite of hardware will be utilized for the ground site portion of this RF link in the Northrop Grumman ITF.

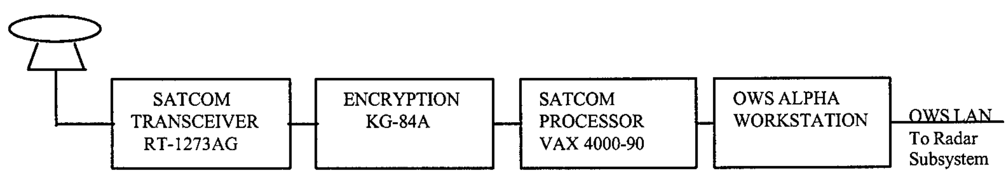


Figure 4.12 Major Hardware Components of the SATCOM Subsystem in the E-8C Aircraft

In addition to the use of this existing SATCOM system hardware, software must be developed to accommodate the special requirements of the JADS/RPSI system. During Phase 1b, the existing E-8C SATCOM hardware, software and operational concepts were reviewed. In current Joint STARS operation, SATCOM usage involves communication between the aircraft SATCOM station and multiple ground stations. The aircraft operates as the primary station and controls the network linking the aircraft to the ground stations. The ground stations are referred to as "secondary stations" and are under the control of the aircraft. Control of the ground stations is effected by polling by the aircraft station. Associated with this polling is a significant reduction in channel efficiency. Most of the data traffic over the network is transmitted from the aircraft and the communication protocol design is heavily biased in favor of the down-link traffic. The up-link traffic to the aircraft generally is limited to a low volume of data. (See reference 11).

For JADS/RPSI the situation is quite different. For JADS, most of the data traffic will be from a single ground site to the aircraft, (to convey the DIS ES PDU, at a nominal rate of 100 PDU/second to the aircraft).The lesser traffic will be from the aircraft to the ground site, (to convey the aircraft ES PDU to the ground site and thence to the DIS network, at a nominal rate of one (1) PDU/second, or less). The JADS RPSI does not require the multi-station polling that is employed in Joint STARS. By eliminating this polling for the RPSI by modification of the SATCOM protocol, significant transmission channel efficiency may be realized. A study will be conducted during Phase 2 to determine the best design modifications for VSTARS.

The existing Joint STARS SATCOM protocol utilizes a Transport Layer application data packing format, which is tailored to the current "contingency enhancements" Joint STARS application. This transport layer currently can accommodate 600 octets of application data. As such, it could accommodate up to 25 stripped (192 bit) PDUs per frame. It is intended that during the planned follow on JADS phases the design of the software for RPSI usage of SATCOM will be preceded by a detailed review of this existing SATCOM software design. Communication protocol, software design, and timing will be reviewed. Then a JADS version can be designed, based on a best mix of existing SATCOM software and any necessary modifications to accommodate the requirement to link PDUs between the aircraft and the ground site at the maximum data rates achievable, consistent with acceptable performance (e.g., data error rates) of the SATCOM link. These issues are discussed further below.

4.2.9 SATCOM Performance Considerations

During the execution of a JADS/DIS "battle scenario" the number of entity state PDU, which the RPSI must receive from DIS, has been estimated at upward to 100 PDUs per second (>19,000 data bits per second, based on 192 bits/PDU, plus overhead). Although this PDU rate is a variable and can be controlled somewhat by judicious design of the scenario, it is desirable to design the SATCOM RF link software, and to select the system parameters and operating modes to accommodate a PDU rate as high as possible, consistent with an acceptable limit on the number of errors in the PDU data.

A useful measure of goodness for the performance or quality of a communications link is the Throughput, e.g., the rate at which data can be transmitted and received at acceptable data or message error rates. For the JADS RPSI SATCOM link, performance can be predicted by a consideration of the design of the hardware and software of the various SATCOM system elements (air, ground and satellite) and of the expected characteristics of the RF transmission paths.

Given the selection of the existing SATCOM system hardware in the aircraft, an equivalent SATCOM system at the ground site, and candidate UHF satellites, the SATCOM link can be analyzed to provide a link budget analysis. The quality of the link can be expressed in terms of the expected signal to noise ratio and the bit error rate (BER) for the total link (i.e., ground site to satellite to aircraft). An example is the space link from the ground site at the Northrop Grumman ITF in Melbourne, FL, to a selected UHF satellite, and then to the E-8C aircraft flying near Fort Irwin in California. Performance can be predicted

as a function of the data transmission bit rate, modulation mode (e.g., BPSK, QPSK etc.,), the details of candidate communications protocol, propagation conditions, and hardware processing parameters..

A preliminary analysis such as this was conducted in Phase 1b for a selected UHF satellite (UHF Follow -On, UFO @ 100 deg. W longitude), a ground station at the Northrop Grumman, ITF in Melbourne, Fl. and an E-8C aircraft flying near Fort Irwin, Ca. The results are shown in Table 4.3. This analysis will be refined in phase 2. For the example postulated parameter set, satellite type, locations of the ground based SATCOM system and the E-8C aircraft, this preliminary analysis indicates a composite Eb/No=9.09 dB, (ratio of the energy per information bit of the input PSK signal to the noise power per Hz.) for the entire link as received by the aircraft.. This corresponds to a theoretical BER performance of approximately $2*10^{-5}$.

The expected message error rate (e.g., the PDU error or loss rate) can be estimated from a consideration of the predicted BER and selected candidate (software) protocols for transmission of the PDU, and the logic which is employed by the software when bit errors occur. As a result of this initial analysis a software design will be selected, implemented, and tested in the Northrop Grumman laboratory with SATCOM system components, in order to confirm the results of the analysis and/or refine the expected performance. It is intended that the planned follow on JADS phase 2 activities will complete this analysis and design and also will include laboratory tests of the RF link, utilizing different modulation methods (e.g., BPSK & QPSK variants) and data rates, and for different versions of available UHF satellites.

The results of these analyses, tests and a recommended software design will be reviewed with the Customer for concurrence in the design and recommended operating mode. This will provide the Customer with an early opportunity to consider tailoring the JADS battle scenario so that the PDU rates are selected to be consistent with the capability of the RF link.

Table 43 Preliminary Analysis of SATCOM Link Budget

SATCOM LINK FROM MELBOURNE, FL to AIRCRAFT
CALCULATIONS near Fort IRWIN, California

a. NOISE TEMP SATELLITE	DEGREES K		290
aa. Rain Effects Tr	DEGREES K		0.00
b. NOISE TEMP Aircraft TEMP	DEGREES K		865.17
c. EIRP SATELLITE MAX	dBw, ENTER DATA		29
d. TEST TONE DEVIATION	kHz, ENTER DATA		NA
e. MAX SIGNALING FREQ	kHz, ENTER DATA	(N/A)	19.2
f. Rec. WAVELENGTH	METERS		1.149425
g. REQUIRED Eb/No for 10^-5	dBw, ENTER DATA	(N/A)	9.65
h. INDEX MODULATION (m)	NO UNITS		NA
i. I.F. BANDWIDTH	kHz	*	25
j. NOISE POWER	dBw		-155.25
k. SNR REQUIRED	dBW		8.503612

****

UPLINK CALCULATIONS	Terminal Melbourne

TRANSMITTED FROM MELBOURNE
(28 deg. N, 80 deg. W)

l. TRANSMIT WAVELENGTH	METERS	1.016949
m. TRANSMIT POWER	WATTS	100
n, TRANSMIT POWER	dBw	20
o. ANTENNA GAIN Tx	dBi	12
p. TRANSMIT EIRP	dBw	32

****

RECEIVED @ SATELLITE (UFO)
(0 deg. N, 100 deg. W)

q. PATH LOSS XMIT	dB		173.2316
r. GAIN OF 1 m SQ ANTENNA	dB/m2		10.84611
s. MISC LOSSES	dB		2
t. OPERATING FLUX @ SATELLITE			-132.386
u. SATELLITE FLUX DENSITY	dbW/m2,	ENTER DATA	-110
v. INPUT BACK-OFF	dB		22.38551
w. SATELLITE Gsat/T (UFO)	dB/k		-14.3
x. MISC. U/L LOSS L	dB		0
y. B/Oi	dB		0
z. C/Nu	dB		27.08897
zz. Limiter Enhancement	dB		3.003747
z1 Cumulative C/Nu + Lim.	dB		30.09272
z2.Eb/No	dB		31.23911
z3 C/No	dB		74.07212

Table 4.3 Continued **RECEIVED AT AIRCRAFT**
(36.6 deg N, 117 deg W)

aa. EIRPs,sat	dBw	29
bb. B/Oo	dB	0
cc. A/C Receiver Gain	dB	2
dd. Gr/T	dB/K	-27.371
ee. MISC LOSS D/L L'	dB	6
ff. EIRP attrib. to carrier	dB	28.99575
gg. C/Nd	dB	7.971866
hh. Eb/No	db	9.118254
COMPOSITE C/N CALCULATION		
STEP 1 C/Nu		1021.579
STEP 2 C/Nd		6.268832
STEP 3 1/(C/Nu)		0.000979
STEP 4 1/(C/Nd)		0.159519
STEP 5 1/(C/Nn) + 1/(C/Nd)		0.160498
gg. COMPOSITE C/N FOR ENTIRE LINK		7.945297
hh. **Composite Eb/No FOR ENTIRE LINK**	dB	9.091685

5. MTI SIMULATION TECHNIQUES

5.1 Application of MTI Pd and TC Statistics

This section is intended to detail the algorithms and techniques which were utilized to implement the Moving Target Indicator (MTI) probability of detection (P_d) and target classification (TC) statistics for the JADS RPSI. The basis of this work was derived from the Phase 1 study for integrating a Radar Processor Simulation (RPS) onto the Joint STARS platform. The results of the study have been incorporated in reference documents 2, 3 and 4.

5.1.1 MTI Pd Requirements

The application of MTI target statistics is fundamentally related to target signal-to-noise (T/N) as derived from the radar range equation modified to include Joint STARS radar subsystem specifics. The Engineering Design Report (EDR) (see reference 3), required radar operating curves to be developed off line. These relate Joint STARS dwell time, azimuth and range to a family of probability of detection (P_d) and T/N levels. The analytical basis of this MTI P_d simulation was derived from a Joint STARS radar performance prediction model (JCONT) developed under the Full Scale Development (FSD) program. JCONT is a non real-time tool which simulates the transmission, reception and processing of a number of coherent processing intervals (CPIs) comprising a set of different pulse repetition frequencies (PRFs) of specified integration length and azimuth beam spacing used to detect and locate a moving target in a clutter background. The target is placed in the desired range and angle location and evaluated over a range of radial velocities. For each CPI, the T/N and T/C ratios are determined for each Doppler filter by convolving the Doppler filter spectrum against the combined clutter, noise and target spectra. From the combined clutter and noise environment, a detection threshold is determined that will allow the system probability of false alarm (PFA) to be met. A Swerling I target model is used with the detection threshold to determine target Pd for each CPI. Assuming each CPI represents an independent look at the target, a composite target P_d is established over 'N' CPIs using an 'M' out of 'N' detection scheme.

5.1.2 Target-to-Noise (T/N) vs Pd

Tests using JCONT indicate that a set of radar operating curves can be developed which accurately relate T/N to P_d averaged over target velocity (Figure 5.3). Since the Joint STARS radar employs a pseudo low, multiple PRF design, some PRFs may be blind in range. The PRFs have been selected such that at most only one PRF will be completely blind in range, so two T/N curves have been developed: one with zero blind PRFs and the other with one blind PRF. When only a portion of the long pulse is lost during transmission, the desired P_d may be interpolated between these two curves.

5.1.3 Target Radial Velocity ($\Re_t$) vs Pd

The relationship of $\Re_t$ to P_d varies based on the set of PRFs used to reduce the effect of target blind speeds near multiples of the PRF. Additional tests using JCONT show that the magnitude of P_d dips over $\Re_t$ are predictable and vary with $^T{}_N$, or equivalently, average P_d. Since the location and magnitude of these P_d dips require an intimate knowledge of the relationship of T/N and T/C in a Doppler filter, this type of processing is beyond the scope of a real-time simulation. Instead, a reference P_d vs $\Re_t$ curve has been developed off line for each PRF set so that the location of P_d dips are known and their magnitude can be predicted using a range rate dip factor to attenuate the dips when average P_d ($\cong$ T/N) is higher than nominal, and to enhance the dips when average P_d ($\cong$ T/N) is lower than nominal.

5.1.4 Determination of T/N

A baseline T/N ratio is defined in dB_m consisting of the constant Joint STARS radar system gains and losses, from which variable gains and losses based on target geometry and scan conditions may be added. T/N_0 consists of classified values for the peak transmit power (P_t), peak antenna transmit gain (G_t), peak antenna receive gain (G_r), processing gain (G_p), transmit duty factor (D_f), wavelength (λ), thermal noise factor (kT), fixed receive chain losses (L_{rcv}), and constant terms [$2(4\pi)^3 = 36\ dB_m$].

$$T/N_0 = P_t + G_t + G_r + G_p + 10\log_{10}(D_f) + 30\log_{10}(\lambda) - kT - L_{rcv} - 36$$

L_{rcv} consists of fixed allocated losses such as radome loss, noise figure, matched filter loss, phase noise, SPP noise, Doppler filter taper, Δ PRF (waveform), and average beam pointing loss.

T/N_0 is modified based on specific target and scan conditions such as the targets radar cross section (σ_t), Doppler filter bandwidth (D_{bw}), target range (R_t), beam broadening loss (L_{scn}), atmospheric loss (L_{atm}), elevation pattern loss (L_{epat}), beam spacing (L_{co}), and lens loss (L_{lens}). Each of these losses are computed based on the geometric relationship of the target to the scan. They are added to the baseline T/N to obtain the following:

$$T/N_t = T/N_0 + \sigma_t - 10\log_{10}(D_{bw}) - 40\log_{10}(R_t) - (L_{scn} + L_{atm} + L_{epat} + L_{co} + L_{lens})$$

Other losses which factor into T/N_t such as $^A{}_D$ quantization loss, filter scalloping loss, pulse loss, and CFAR losses vary according to PRF and Doppler filter and is therefore compensated for through application of the range rate dip factor ($\Re_f$).

5.1.5 Determination of Target Pd (Pdt)

After modifications to T/N_t are made, the target's average P_d over $\Re$ (AP_{dt}) is interpolated from the radar operating curves which relate P_d to T/N. From the AP_{dt} a range rate dip factor $\Re_f$ is computed to determine the actual P_d statistic of the target at its radial velocity $\Re$ and then applied as follows to derive the target's actual P_d (P_{dt}).

$$\Re_f = 1 + 10\log_{10}(AP_{dr} / AP_{dt}) \qquad P_{dt} = AP_{dt} + \Re_f \times (P_{drt} - AP_{dr})$$

where,

AP_{dr} : P_d averaged over $\Re$ for the reference waveform.
AP_{dt} : P_d averaged over $\Re$ for the target interpolated from ${}^{T}{}_{N}$ curves.
P_{drt} : P_d for the target from the reference curve at $\Re_t$.

5.1.6 Computations Made Per 4x4 Km Grid

A grid filtering technique is used to check for virtual targets within the radar beam footprint by first quantizing all virtual targets within grids of 4x4 Km. When the set of 4x4 Km grids within the beam have been selected, some pre-processing of MTI P_d statistics are accomplished at the grid level. Since this represents very low resolution data, information about this area cannot change rapidly with respect to the scan. The computations made per grid are L_{atm}, L_{epat}, and L_{lens} and are applied equally to all targets within the grid.

Atmospheric loss (L_{atm}) is a significant T/N loss due to the attenuation of the radar energy through variable atmospheric conditions. Following the Joint STARS System Specification, there are three types of weather conditions modeled: (1) clear air, (2) clouds, and (3) rain. For rain conditions, a rain rate in mm/hr is defined. Future implementations of weather PDUs on the DIS network will allow for more flexibility concerning weather, but for this phase of JADS, the operator specifies one of these weather conditions (Later we might want to consider a graphical user interface (GUI) which will allow the operator to define weather regions mapped to grids). L_{atm} is the sum of clear air, cloud, rain + cloud and rain losses over which the beam travels both ways through the boundaries of each weather strata. The boundaries of weather strata are separated by altitudes from which the beams projection through each layer is computed and a constant loss (per Km) for each weather strata is applied over twice the distance through the layer. The clear air loss is applied for the entire two way propagation path and is currently available in subroutine SKRS90_ALOSS. The cloud loss is defined as 0.026 dB/Km (from the Joint STARS System Specification) and is applied for the two way propagation length through clouds if the weather type indicates cloud or rain conditions. The rain loss is defined from Nathanson (Reference 9) as $0.00809rr^{1.285}$, where 'rr' represents the rain rate in mm/hr. Subroutine MTISIM_ATM_LOSS defines the mathematics used to compute these losses using platform altitude, latitude, target range, and grid weather as inputs.

Elevation pattern loss (L_{epat}) occurs when the target is offset from the antenna elevation boresight and is particularly apparent for small targets (such as the double Doppler component of the TC mode). Given the platform altitude/orientation and the antenna orientation (A-Matrix), the elevation boresight range is computed for the dwell. The range of the grid center is checked against a Taylor weighted beam approximating the actual antenna elevation pattern to determine the elevation pattern loss for all targets within that grid. Analysis subroutines TAYLOR1 and SANTVP are utilized to determine L_{epat}.

Lens loss (L_{lens}) is a radar refraction loss which makes the atmosphere behave like a negative lens, resulting in the reduction of the targets apparent size. L_{lens} is interpolated from a family of curves relating grazing angle and target (i.e. grid) range derived from the January 1973 IEEE paper on Atmospheric Lens Effect. Analysis subroutine LENSLOSS is available.

Typical losses for a clear weather single swath condition are as follows:

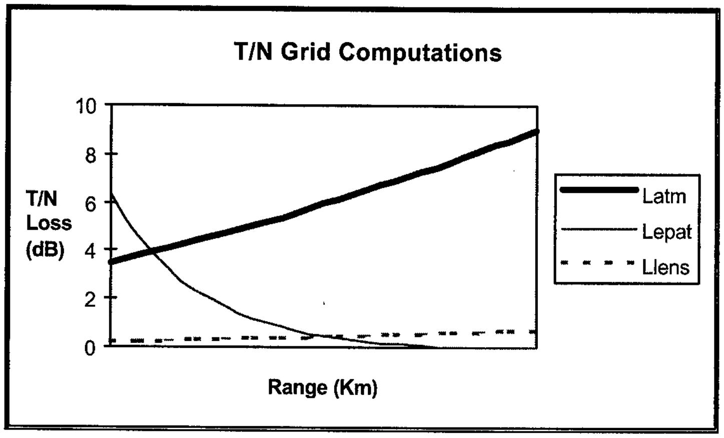


Figure 5.1 Typical Radar Losses for Clear Weather

5.1.7 Computations Made Per Dwell

Some radar system losses vary only as the beam scans in azimuth and can be considered the same for all targets within that beam.

The beam broadening loss (L_{scn}) occurs from electronically steering the beam in azimuth, and for the Joint STARS antenna is represented by the closed form expression:

$$L_{scn} = -20\log_{10} (5.67\cos^{0.5}\theta_s - 2.36\cos\theta_s - 2.31)$$

where,

θ_s : antenna scan angle with respect to boresight (radians) = $\pi - \beta_s$.
β_s : antenna cone angle with respect to platform heading (radians).

In the Joint STARS radar design, the Doppler filter bandwidth (D_{bw}) and azimuth beam spacing varies as a function of θ_s. The T/N curves were derived under the assumption that a nominal D_{bw} and two-way 6 dB beam spacing were used. The actual D_{bw} can be derived from the number of integrated pulses (N_{int}) and PRF in the first CPI of the dwell as

$$D_{bw} = \lambda \text{ PRF} / (2 N_{int})$$

A beam spacing factor (BS_f) can be computed to relate the actual beam spacing back to the two-way 6 dB beam spacing. From this factor an additional beam spacing loss (L_{co}) analogous to the azimuth beamshape loss can be derived as follows:

$$L_{co} = -10\log_{10}(BS_f) \qquad BS_f = \phi_d \cos\theta_s / \phi_b$$

where,

ϕ_d : Beam spacing for the current dwell (radians).

ϕ_b : Two-way 6 dB beam spacing at broadside (radians).

Typical losses for a dwell as a function of angle are as follows:

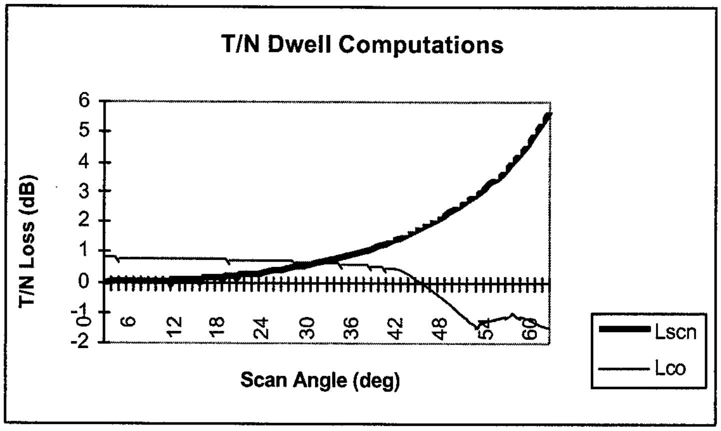


Figure 52 Typical Radar losses for Dwell vs Angle Computations made per Target

5.1.8 Computations Made Per Target

Computations made per target are the lowest resolution required for the MTI P_d simulation. The computations made per target are target range (R_t), range rate ($\Re_t$), radar cross section (σ_t), terrain screening, and target resolution.

The loss due to target range is $40\log_{10}(R_t)$. Target range is given by:

$$R_t = [\,(T_x - P_x)^2 + (T_y - P_y)^2 + (T_z - P_z)^2\,]^{0.5}$$

where,

$\bar{T}$: Target Position Vector (in TCS)

$\bar{P}$: Platform Position Vector (in TCS)

Target range rate ($\Re_t$: radial velocity) is derived to determine if the target is in a P_d notch due to Doppler ambiguities within the PRF set. Since the P_d dips are considered the same for opening and closing targets, the absolute value of $\Re_t$ is used.

$$\Re_t = -\overline{V}_t \bullet (\overline{T} - \overline{P}) / R_t \qquad \overline{V}_t : \text{Target Velocity Vector (in TCS)}$$

Target radar cross section (σ_t) is expressed in dB_m as $10\log_{10}(RCS_t)$ when RCS_t is expressed in m^2. σ_t will be the default value for primary targets in the Joint STARS System Specification For TC statistics, the smaller double Doppler σ_t is used.

Target screening occurs when a target is obscured along the radar line-of-sight by a physical object. Determination of target screening is done by comparing the target line-of-sight to the platform with the target line-of-sight in the Area Visability Database (AVD). Subroutine STCAH0_GET_TAN_RTE accesses the AVD and reports back the target line-of-sight to the horizon based on the azimuth angle.

Target resolution effects target detection in range, azimuth and Doppler space. When two or more targets are located within close proximity, the radar can only detect one of those targets. Due to the scanning nature of the Joint STARS MTI design, target resolution constraints in azimuth and Doppler space are rare because the target can be seen by multiple CPIs at different azimuth angles, so it is not necessary to model these constraints. The primary constraint on target resolution is the distance between targets in range. Formal system level tests require a target to be at least 1.5 range bins from another target to insure detection capability, but a target may be detected when closer. Variable range resolution effects can be modeled by uniformly selecting a range resolution based on range bin size between 0.75 and 1.5 range bins for each radar dwell.

5.1.9 Data Analysis

In order to evaluate this modeling technique, two data analyses have been performed. First, a theoretical simulation environmental test was performed to evaluate this technique against the non-real time analysis tool JCONT. The second analysis compares the technique with actual flight data taken under controlled conditions.

5.1.9.1 JCONT Simulation

The advantage of performing a comparison with a theoretical test environment is that all conditions can be controlled. In this analysis, 100 test points were randomly selected in range, azimuth, and weather, with all other variables set to a nominal value. The average Pd of the real-time simulation (JADS) is compared with the non-real-time simulation (JCONT). The statistics show that the average Pd error is 1.0% with a standard deviation of 1.7% and the average T/N error is 0.3 dB with a standard deviation of 0.3 dB. The results are indicated below in Figure 5.3

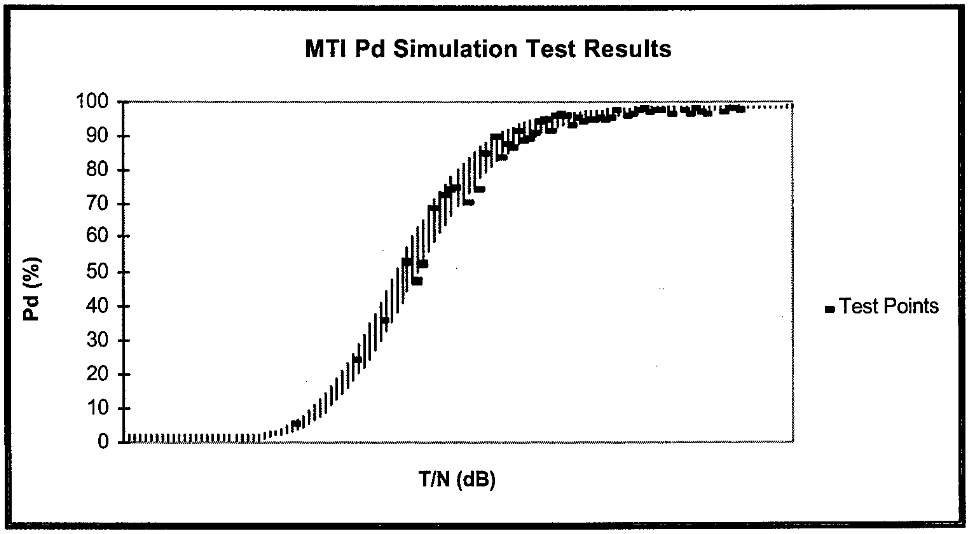


Figure 53 Compares Pd v.s. T/N of JADS & JCONT Simulations

5.1.9.2 Flight Data

Analysis of flight data requires as many variables as possible to be controlled, but there are always unknown system conditions. Formal system level tests are designed to maximize control over the variable conditions of the test, so these tests represent the best data set for comparison of the JADS simulation to the actual system. A brief comparison between SLPV flight data and the JADS simulation is shown below for twelve distinct SLPV Test Points. The JADS estimate of Pd assumes *clear weather* conditions and a *nominal sized target* with a Swerling I radar cross section fluctuation. The chart shows that the JADS estimate of Pd was slightly more optimistic than the flight data (on average about 3-4%), which can easily be attributed to errors in the assumptions of variable target size and clear weather conditions.

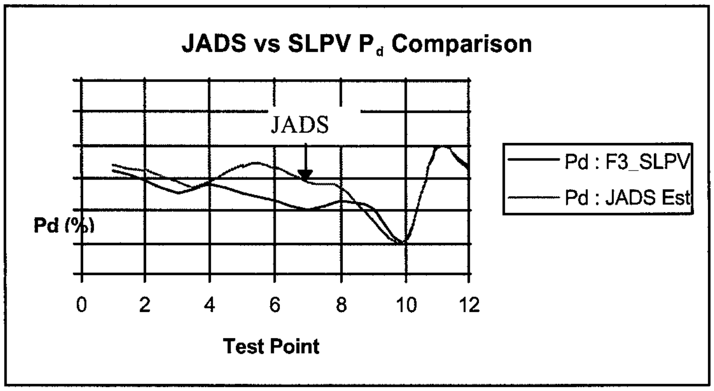


Figure 54 Compares Pd of JADS and SPLV

5.2 Application of MTI CEP Statistics

This section is intended to detail the algorithms and techniques which were utilized to implement the Moving Target Indicator (MTI) location accuracy statistics for the Joint Advanced Distributed Simulation (JADS) environment on the Joint STARS platform. The location of targets detected by the Joint STARS radar are reported relative to the local Topocentric Coordinate System (TCS) after coordinate conversion from range and angle. Location accuracy is measured and applied using the Circular Error Probability (CEP) method based on the targets reported position versus its true position.

An overview of the MTI location error sources is provided as background for the JADS CEP algorithms. From these error sources, a two dimensional linear model of down range and cross range errors relates traditional 1σ values to target CEP. The down range, cross range, and CEP statistics observed during controlled flight tests are then codified to the JADS CEP algorithms and applied to the JADS virtual targets based on their true range and angle.

5.2.1 MTI CEP Error Sources

The application of MTI target location error statistics is derived from the 1σ errors in range, cone angle, vertical separation and coordinates. Range error sources include radar range measurement, residual refraction and hardware. Cone angle error sources include interferometric measurement and boresight corrections. Vertical separation errors primarily derive from platform altitude and the hypsographic database. Coordinate error sources include navigation position and coordinate conversion. The geometric parameters outlining the error sources are defined as follows:

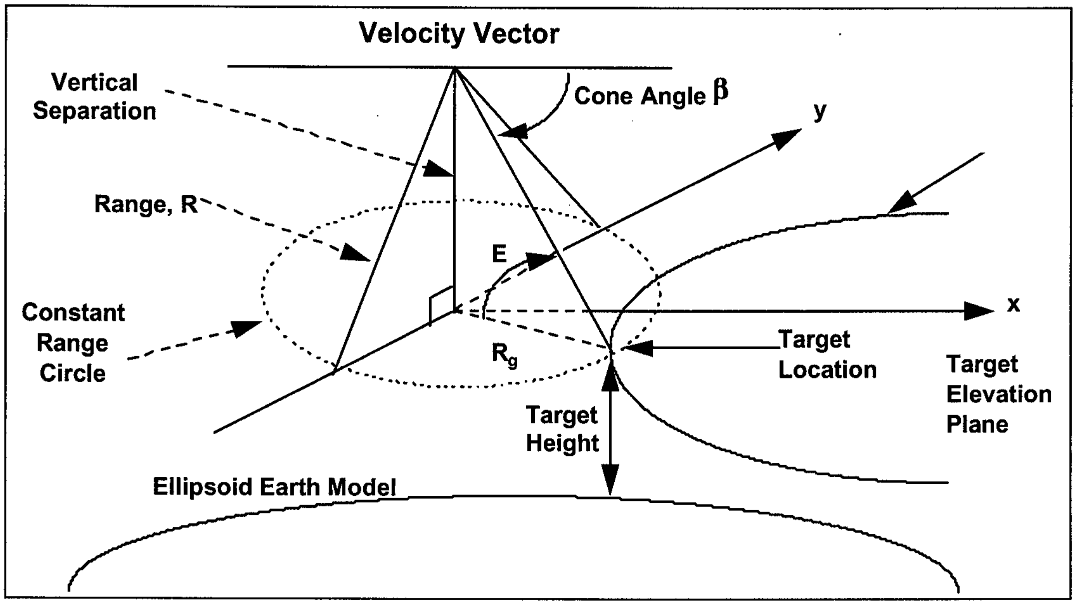


Figure 55 Defines Error Source Parameters

The CEP error sources are input into a linear model with two outputs; a down-range error and a cross-range error, where each output is a linear function of individual error contributors. The 1σ value of the individual error contributors are RSS'd, and CEP is calculated for the uncorrelated down range and cross range variables as:

- X=min(Xr,Dr) Y=max(Xr,Dr)
- Linear region: X/Y>0.4: CEP = 0.560Y + 0.617X
- Quadratic region: X/Y<0.4: CEP = $0.674Y + 0.128X + 0.513X^2/Y$

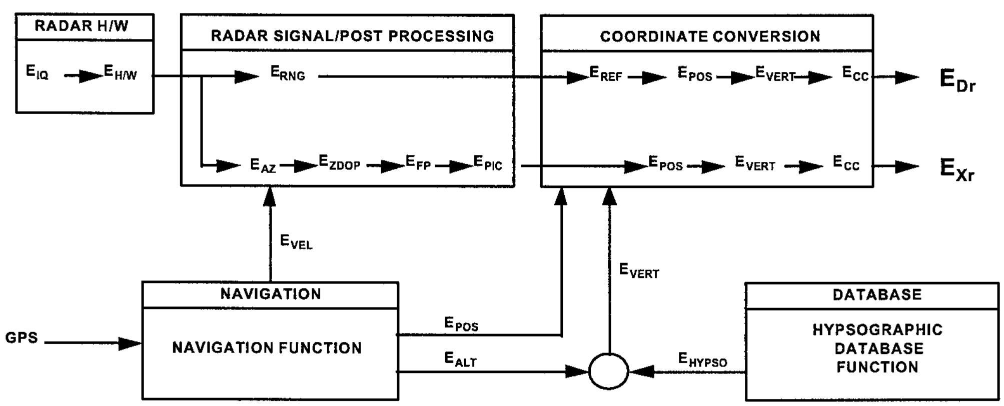


Figure 56 MTI Location Error Model

The down range error model is be derived from the 1σ individual contributors as shown below:

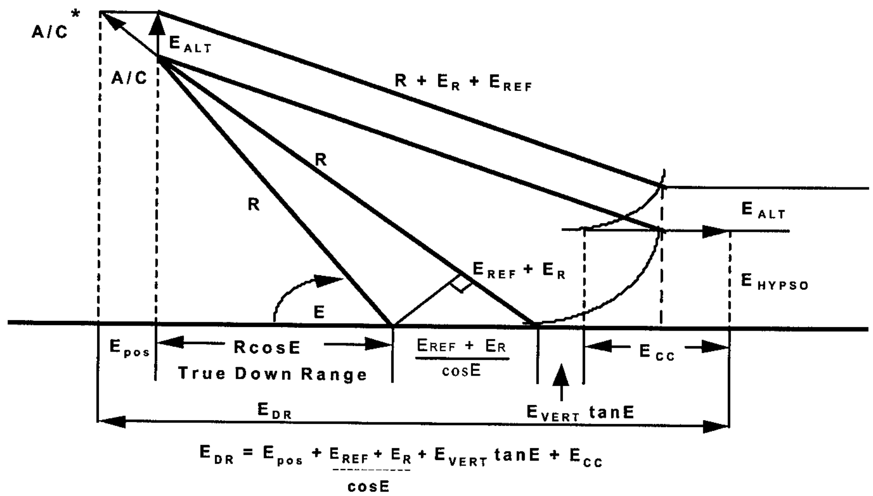


Figure 57 MTI Down Range Error Model

The cross range error model can be derived from the 1σ individual contributors as shown below:

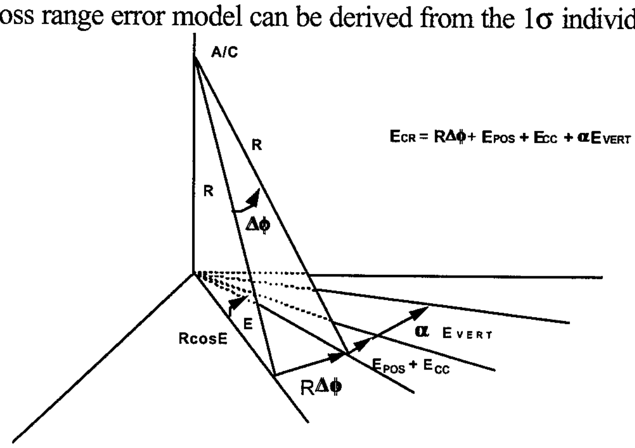


Figure 58 MTI Cross Range Error Model

5.2.2 Data Analysis

The 1σ down range and cross range errors can be derived from a theoretical model as described in the previous paragraph and from flight data taken under controlled conditions.

5.2.2.1 Location Error Budget

From the allocated location error budget, target CEP is derived as a function of range and angle, and is used as the basis of location accuracy measurement. The following diagram illustrates the CEP curves for a 60° scan angle.

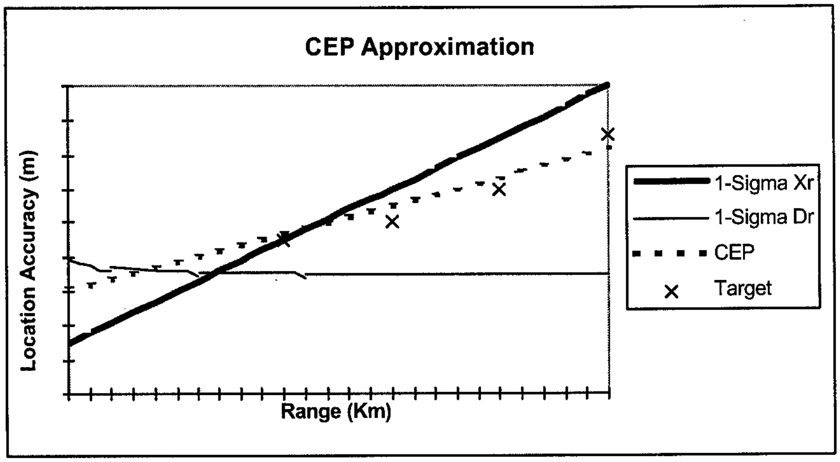


Figure 5.9 Theoretical Location Accuracy

Analysis of controlled SLPV flight data provides the best insight into the actual target location errors. Controlled test conditions at variable range and angle combinations yield an approximate CEP model as a function of range and angle from which the 1σ down range and cross range errors may be decorrelated. The following diagram illustrates the CEP curves for a 60° scan angle.

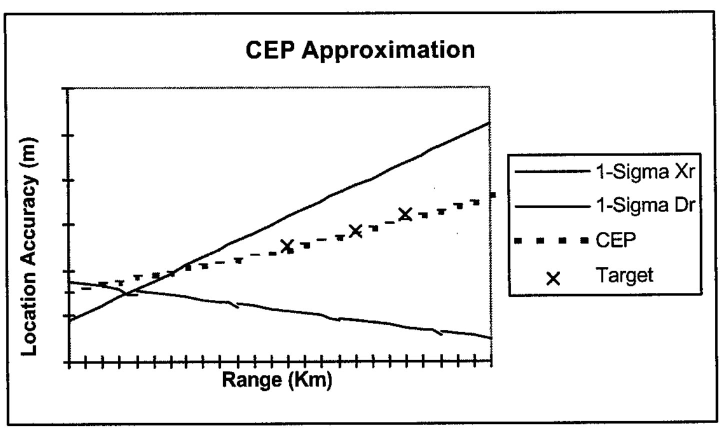


Figure 5.10 Location Accuracy from SLPV Flight Data

Further analysis of this data shows that there are four variable statistics which contribute to this CEP approximation;

- a location error bias,

- a random Gaussian distribution about the mean,
- a random exponential distribution extending beyond the tails of the Gaussian distribution (cross range only),
- and a uniform random distribution extending beyond the tails of the Gaussian distribution (down range only).

Each of these effects can be seen in the following diagrams.

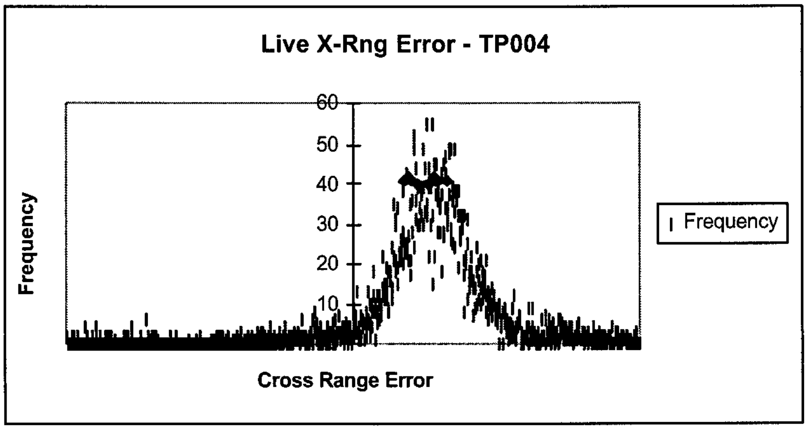


Figure 5.1 Distribution of Errors from Flight Data

JADS simulation routines have been successfully executed against SLPV test points, showing positive results:

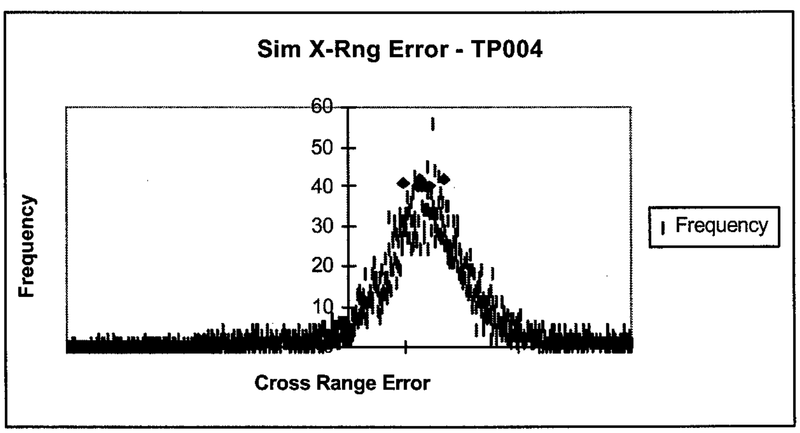


Figure 5.2 Distribution of Errors from JADS Simulation

5.2.2.2 Determination of Target Position

Once the down range and cross range errors have been established for a given range and angle combination, these statistics must be applied randomly to determine the reported target location. Analysis of flight data indicates that location errors consist of a variable bias, a Gaussian distribution about the mean, and an exponential/uniform distribution extending beyond the Gaussian tails.

To avoid a simulation-like appearance, each of these characteristics must be modeled in the JADS simulation. This is accomplished by first forming the fundamental CEP ellipse using the theoretical 1σ down range and cross range errors for that range and angle condition (as derived from flight data analysis).

- Location Bias: A phasor is used to model the location error bias by slowly moving the center of the error distribution inside the CEP ellipse. Through observation of the SLPV flight data, the magnitude of the phasor is approximately one fourth of the 1σ value. The phasor is incremented each dwell so that all targets within the current dwell have the same bias. The phasor's rotation rate varies randomly per revisit to the RSR.
- Gaussian Distribution: Further reduction of flight data shows that 95% of the targets are Gaussian distributed in the down range component and 80% of the targets are Gaussian distributed in cross range component. A uniform random number determines if the target is Gaussian according to these percentages. If the target is Gaussian distributed, then a Gaussian deviate is formed and applied to the computed 1σ value for that target.
- Exponential Distribution (Cross Range): If a target is selected to be exponential, then an exponential distribution is applied in the region extending beyond 1.5 sigma (uniformly positive and negative), so that it dove tails with the Gaussian distributed targets.
- Uniform Distribution (Down Range): If a target is selected to be uniform, then a uniform distribution is applied in the region extending beyond 3.0 sigma (uniformly positive and negative), so that it dove tails with the Gaussian distributed targets.

Once the magnitude of the target's down range (E_{dr}) and cross range (E_{xr}) error has been established, the true TCS position (T) of the target is modified as follows along the radar line of sight (T-P):

$$Az = Tan^{-1} [(T_y - P_y) / (T_x - P_x)]$$

$$\bar{P} = \bar{P} + [D]*[E] \qquad [D] = \begin{bmatrix} Cos(Az) & -Sin(Az) \\ Sin(Az) & Cos(Az) \end{bmatrix} \quad [E] = \begin{bmatrix} E_{dr} \\ E_{xr} \end{bmatrix}$$

5.3 Application of MTI Radial Velocity Statistics

This section is intended to detail the algorithms and techniques which were utilized to implement the Moving Target Indicator (MTI) radial velocity accuracy statistics for the Joint Advanced Distributed Simulation (JADS) environment on the Joint STARS platform.

Radial velocity is measured by the Joint STARS radar using a velocity decode algorithm based on an "M" out of "N" coherent processing interval (CPI) scheme. Each CPI uses a different pulse repetition

frequency (PRF) designed such that Doppler blinds and foldovers can be mitigated with detection by other PRFs. The radar also reports a radial velocity quality flag indicating that the radar has a high or low confidence in the accuracy of the reported radial velocity. The quality flag is based on the number of CPIs used to detect the target ("M").

5.3.1 Data Analysis

Radial velocity quality and error statistics have been derived from data collected under controlled conditions during SLPV flight tests. Analysis of controlled SLPV flight data provides the best insight into the actual target radial velocity errors that can be modeled for the JADS simulation.

5.3.1.1 Radial Velocity Error

Controlled test conditions at variable range and angle combinations show that the reported radial velocity contains an error distribution which is independent of range and angle test conditions. The data indicates that 93% of the reported targets form a Gaussian distribution about a mean generally shown to be 0. The remaining 7% of the targets form a uniform distribution beyond 2.5σ. The uniform distribution appears to have two levels, where approximately 80% of the uniformly distributed velocity errors (0.8*7%=5.6% of all detected targets) lie within 15σ. The wild points (7-5.6=1.4% of all detected targets) consistently appear in each controlled test point. Figure 5.13 illustrates the radial velocity error profile from SLPV flight 049 from which the JADS simulation was derived. The corresponding profile for the JADS simulation results is exhibited in Figure 5.14.

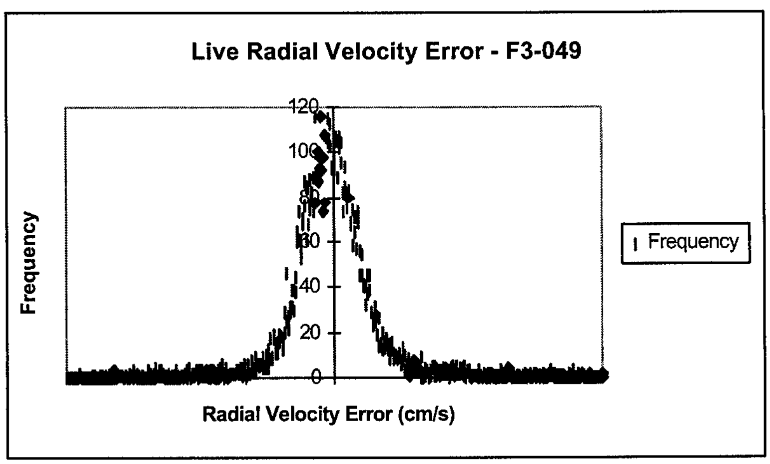


Figure 5.13 Distribution of Radial Velocity Errors From Flight Data

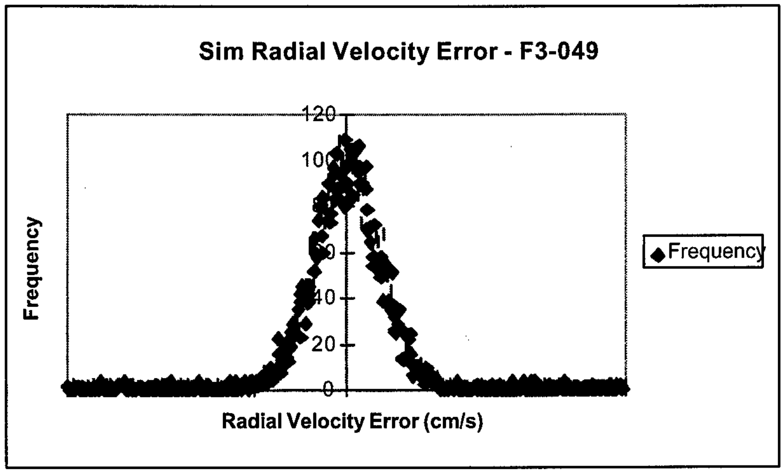


Figure 5.14 Distribution of Radial Velocity Errors From JADS Simulation

5.3.1.2 Radial Velocity Quality

Analysis of the radial velocity quality flag shows that the reported radial velocity quality is highly correlated with the probability of detection (P_d) for each of the test points. This seems logical since Pd is also based on the "M" out of "N" CPI detection scheme. Therefore the radial velocity quality flag should be randomly selected based on the target's Pd. The radial velocity error profile for good quality targets is marginally better than that of poor quality targets.

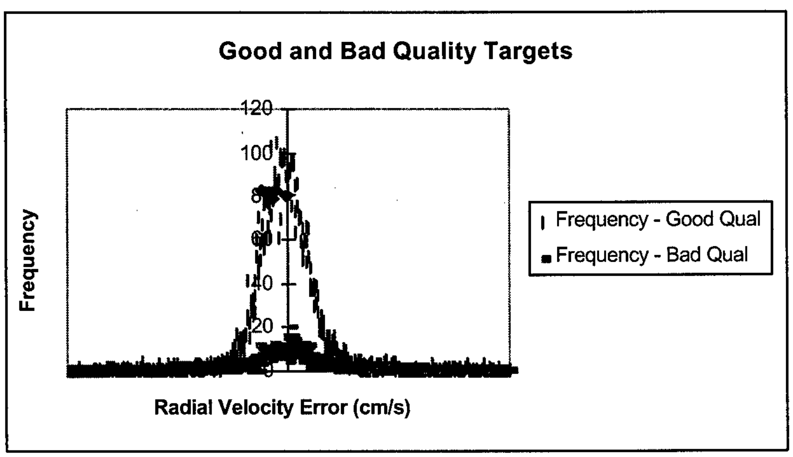


Figure 5.15 Distribution of Radial Velocity Errors for Good and Bad Quality Target

6. JADS Communications Connections At Northrop Grumman Integrated Test Facility (ITF)

JADS is being developed in multiple phases. The general concept of operation for Phase 1 of the Joint STARS JADS project has been as follows:

- The JADS system was developed in the lab environment on the Alpha 600's workstations These computers receive DIS virtual targets PDUs via a T1 line from White Sands Missile Range (WSMR) via Kirtland AFB which is connected to the laboratory setup for data monitoring purposes. An SGI workstation is used to log the PDU data files which are received over the DIS WAN (T1).

- The target/war simulation, JANUS operates at the White Sands Missile Range (WSMR), generating virtual targets and issuing Protocol Data Units (PDUs) on the Distributed Interactive Simulation (DIS) network.

- The Radar Processor Simulation Integrator (RPSI), which executes on the Alpha 600's computers, receives the virtual target information, via entity state PDUs which are received from the DIS network, or replayed from the SGI workstation. The ALPHA 600s are connected to an Ethernet LAN which in turn interfaces with the T-1 line via an IDNX and an KIV-7 encryption device. The RPSI supplies virtual target radar reports combined with the live target radar reports (MTI and SAR reports) to operator work stations and to a SCDL emulation.

- At present for JADS, a single T1 communications service line is connected into the Northrop Grumman Integration and Test Facility (ITF) building 222. This line provides for the incoming simulation data (PDUs) and outgoing messages to and from the TCAC at Kirtland AFB. A second T-1 service (currently not in service) was utilized for transmitting SCDL data (MTI and SAR Target reports) to, and receiving Radar Service Requests (RSR) from an Army ground station module, (GSM or a replica, GSMR), at Motorola in Phoenix, Arizona. A third T-1 service (yet to be connected) will be connected during the next phase, to establish a link to a GSMR at Fort Hood

- Connections were established so that the PDU files in the SGI (located on the second floor of the ITF, in room 209) can be routed to the ITF Classified LAN which connects to the Northrop Grumman Operations and Control Test Laboratory (OCTL) which is located on the fourth floor of the ITF. The JSTARS Prime Mission Equipment (PME) is located in the OCTL and normally is connected to this LAN. The ALPHA 600 computers can also be connected to this LAN.
- Connections also were established for a third LAN, so that the ALPHA 600 computers can be connected to two of the operator workstations (OWS) of the JSTARS PME in the OCTL.

These wiring connections internal to the Northrop Grumman ITF are shown in Figure 6.1. Figure 6.3 illustrates the connections between and major equipment in the Northrop Grumman ITF and in the other DIS facilities utilized by the JADS JTF.

6.1 Secure Voice Communications

A direct secure voice communication connection via T1 lines from the Northrop Grumman ITF in Melbourne, Fl to the TCAC in Albuquerque, NM, enables continued direct communication between ITF and the TCAC during the execution of planned JADS tests.

The direct telephone voice communication link utilizes one of the 24 sub channels from one of the secure T1 lines which connect between the ITF and the facilities at Albuquerque NM. A circuit card (a Quad Analog Voice Card) was installed in the existing IDNX.. (see Figure 6.1). The IDNX functions as a demultiplexer and the circuit card enables the use of one sub channel from the T1 channels, for use as the voice phone channel.

An electronic Voice Signal Converter provides for voice transmission over the multiplexed digital data link.

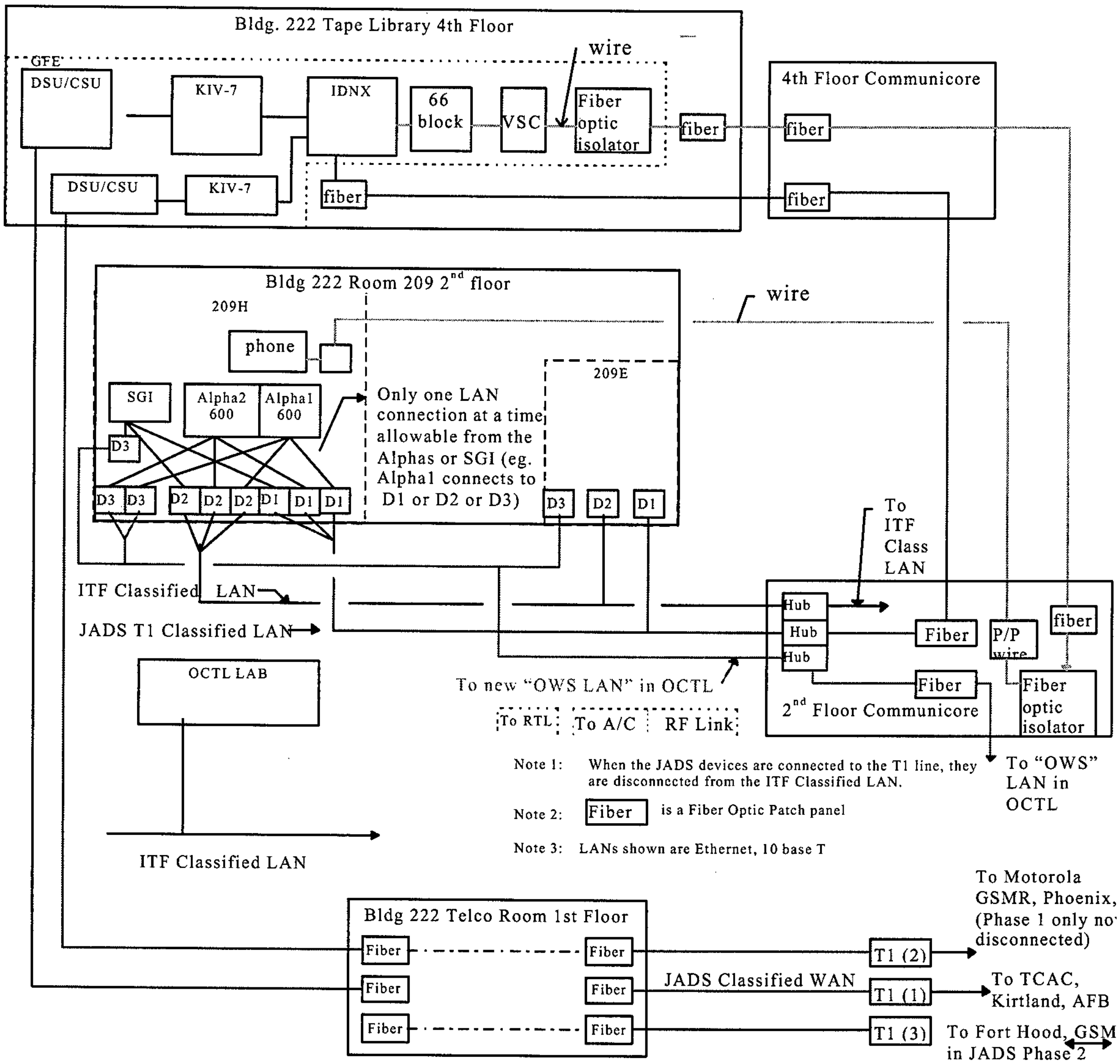


Figure 61 JADS Communications Connections In Northrop Grumman ITF

6.2 Equipment Description and Utilization

The following describes the equipment and its use:

The Alpha 600 workstations are known as "JADS01" and "JADS02", Each is equipped with a single 333-Mhz CPU. One is equipped with 512 of RAM, the other with 1 GByte of RAM. The operating system is DEC OpenVMS Version 7.0. The JADS RPSI software executes in this equipment.

The SGI Workstation, known as "grumman", functions as a DIS PDU logger/replayer and as a Video Teleconferencing Device (VTC).

The two Verilink CSU/DSU devices function as the Channel Service Units / Data Service Units for converting the T1 line signals for input into the KIV-7 HS crypto devices.

The two Allied Signal KIV-7 HS Crypto devices function as the encrypters/decrypters.

The Network Equipment Technologies IDNX/Micro 20 device (Part number 01-53405) functions as the multiplexer. The IDNX splits the signal coming in from the Northrop Grumman JADS system, using the CISCO 7000 software, and routes the outgoing messages according to their addressed destinations which are:

- The SCDL which interfaces with the Motorola GSMR. and,
- The DIS interface to the JANUS scenario generator at WSMR, NM via the TCAC at Kirtland AFB, Albuquerque, NM.

The Voice Signaling Converter is a RAD Data Systems device (290100000G) which enables connection of voice equipment to data communications equipment, and provides voice transmission over a multiplexed data link.

6.3 Connections to Provide for Developmental Testing of the TADIL J U Tracker Algorithms

Additional connections were established to accommodate the TADIL-J Upgrade (TJU) program software developmental testing of new target tracking algorithms using the JADS RPSI. The TJU connections are shown in Figure 6.2. These connections permit the OCTL trellis and associated workstations to be connected to the JADS scenario PDU playback assets (the SGI workstation) , to support the algorithm tests. They also permit an Alpha Station 500 workstation to be connected to the JADS scenario playback assets. This workstation is utilized for TJU tracker algorithm development and test. In addition the JSTARS PME computer systems in the OCTL trellis can be connected to an alternate, isolated network segment which was installed for the JADS program. The TJU connections provide the capability to connect the entire trellis OWS LAN to the JADS isolated LAN ("D3") segment. The JADS systems will not be connected to their external T1 links when the OCTL trellis mission computers are attached. This is protected by the manner in which the alternate LAN's are

connected (i.e. only the isolated JADS segment are available to the trellis; the external segment are accessible to the JADS computers when they are off-line from the isolated LAN segment).

These TJU systems can be connected to each other and to other computer assets by means of the isolated JADS "D3" Ethernet network segment in the ITF. Trellis assets may be connected to the laboratory OWS LAN or to the isolated JADS LAN segment via the OCTL patch panel area housed in the STL. The ALPHA 500 workstation has an alternate patch block installed for the alternate, isolated LAN.

Data link protection is provided by the security approved network supported by the IS department and DSSD. Isolation from the external JADS T1 link is provided by a IS/Networks-supplied patch panel on the second floor in the JADS asset area. These connections are maintained by the NG IS department and DSSD. IS/Networks provide and maintain the network hubs and supply data necessary for security approval of network assets.

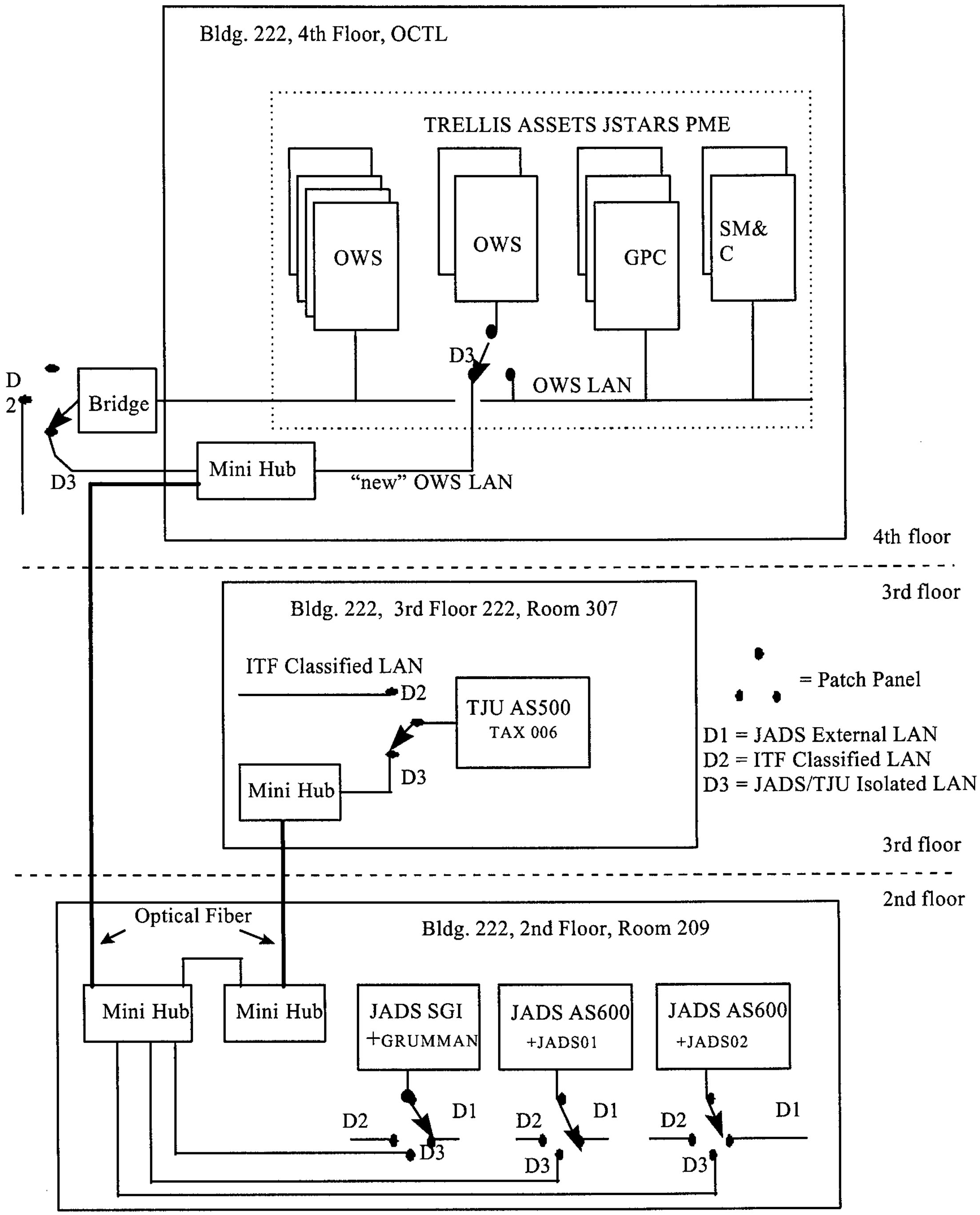


Figure 6 2 JADS Connections for TADIL J U (TJU) Developmental Tests

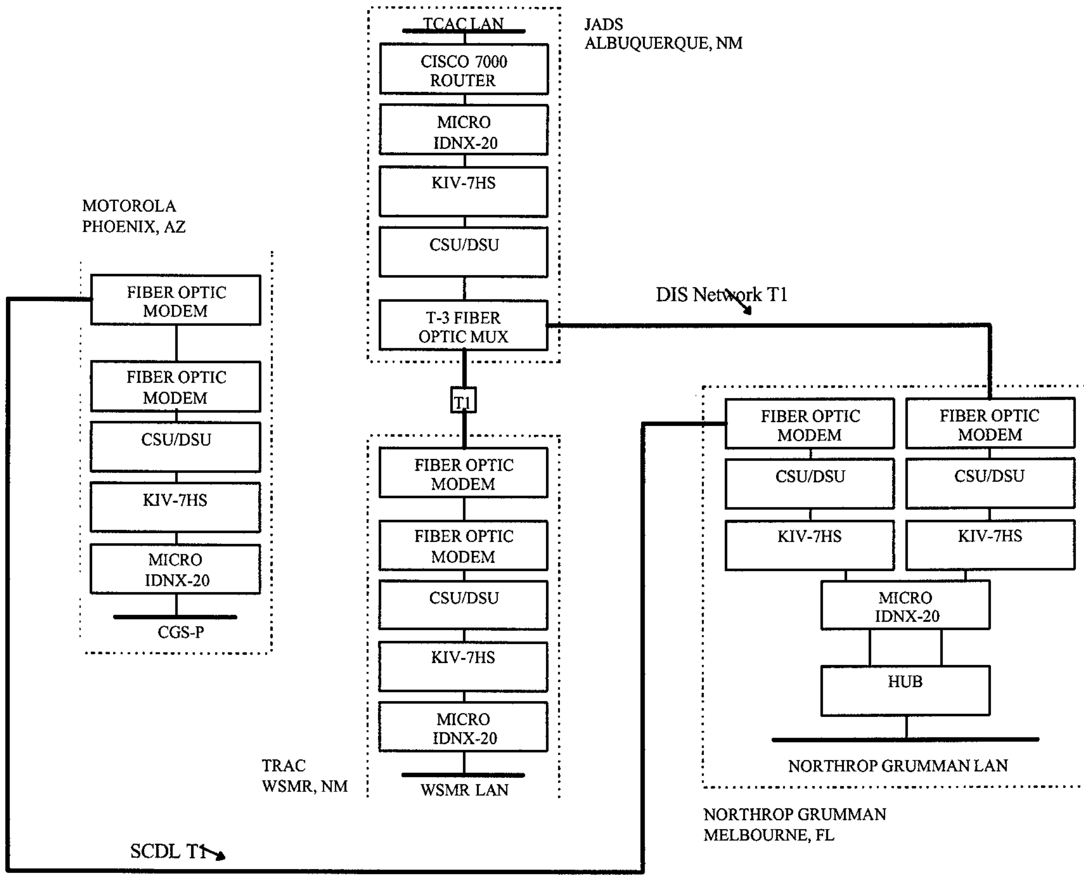


Figure 63 Communications Diagram for JADS/VSTARS

7. Reference Documents

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3. ENGINEERING DESIGN REPORT (EDR) for the RPS (JADS RPT 002)
4. A REAL TIME STOCHASTIC MTI RADAR SIMULATION for DIS APPLICATION. IN AIAA FLIGHT SIMULATION TECHNOLOGIES, Technical Papers San Diego, Ca., July 1996 Proceedings. By Richard Floto, Northrop Grumman.
5. ARIES RPSI INTERFACE CONTROL DOCUMENT for the ADVANCED RADAR IMAGING EMULATION SYSTEM, by Lockheed Martin TDS, Feb 1997.
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8. RADAR DESIGN PRINCIPLES, SECOND EDITION, McGraw-Hill, by Nathanson, Fred E.
9. PRELIMINARY PERFORMANCE ASSESSMENT REPORT for PHASE 1, VIRTUAL SURVEILLANCE TARGET ATTACK RADAR SYSTEM, (VSTARS), Northrop Grumman document number C99SR078 dated, Jan/1998
10. INTERFACE DOCUMENT for the JOINT STARS SATCOM CONTINGENCY ENHANCEMENTS, (Protocol Version1)—DRAFT, Dated Jan 17/97, Prepared by NG for OWS Contract F30602-96-C-0233, ERF A-6-1589.

APPENDIX E

Final Report

for the

Advanced Radar Imaging Emulation

System (AIRES) Program

FINAL REPORT

for the

ADVANCED RADAR IMAGING EMULATION SYSTEM (AIRES) PROGRAM

Contract Number:: F33615-95-C-1610

30 September 1997

Prepared for:

Joint Advanced Distributed Simulation - Joint Test Force

and

Air Force Wright Laboratory

Lockheed Martin Tactical Defense Systems
Post Office Box 85
Litchfield Park, Arizona 85340-0085

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1. Introduction

The Joint Advanced Distributed Simulation End-to-End (JADS ETE) team has funded Lockheed Martin TDS Arizona to develop a Synthetic-Aperture Radar (SAR) simulation that emulates the Joint STARS SAR operation. This simulation system is referred to as the Advanced Radar Imaging Emulation System (ARIES) and is operationally embedded into Northrop Grumman's Radar Processor Simulation Integrator (RPSI). The RPSI integrates the Distributed Interactive Simulation (DIS) environment with a simulated SAR and moving-target indication (MTI) capability. This integrated system is known as the Virtual Surveillance Target Attack Radar System (VSTARS).

The development of the ARIES has been designed as a two-phase effort. Phase I of the ARIES program identified the system requirements, determined software interfaces between the RPSI and ARIES, and identified the process by which to integrate real-world topographical and feature databases. This design was presented to the government at the end of Phase I and accepted at a formal Acceptance Design Review. Phase II is defined as the implementation and testing of Phase I design. This final report covers our approach and performance of Phase II.

2. Technical Overview

The ARIES project utilized a time-phased development approach creating three distinct software builds. Each build provided increased functionality and verified that requirements were met. This incremental development approach was designed to minimize the integration and performance risk associated with emulating a JSTARS SAR by providing feedback from the customer in regards to the various stages of the development.

The ARIES program is an enhancement to the SAR simulation capabilities previously demonstrated by the XPATCHES simulation. XPATCHES is a non-real time, high fidelity, multispectral simulation tool. ARIES emulates the radar operational parameters of the JSTARS SAR sensor in real-time with the added capability of using real-world databases such as DTED and DFAD.

The software development was guided by a prototype approach to determine algorithmic results and execution performance levels before detailed code was written. As most of the design was graphical dependent, software development tools, such as PV-Wave, were used to assess the validity of algorithm development. This instituted an effective methodology for data analysis, image processing, and the use of tabular manipulation for record-based data used in real-time application and optimization.

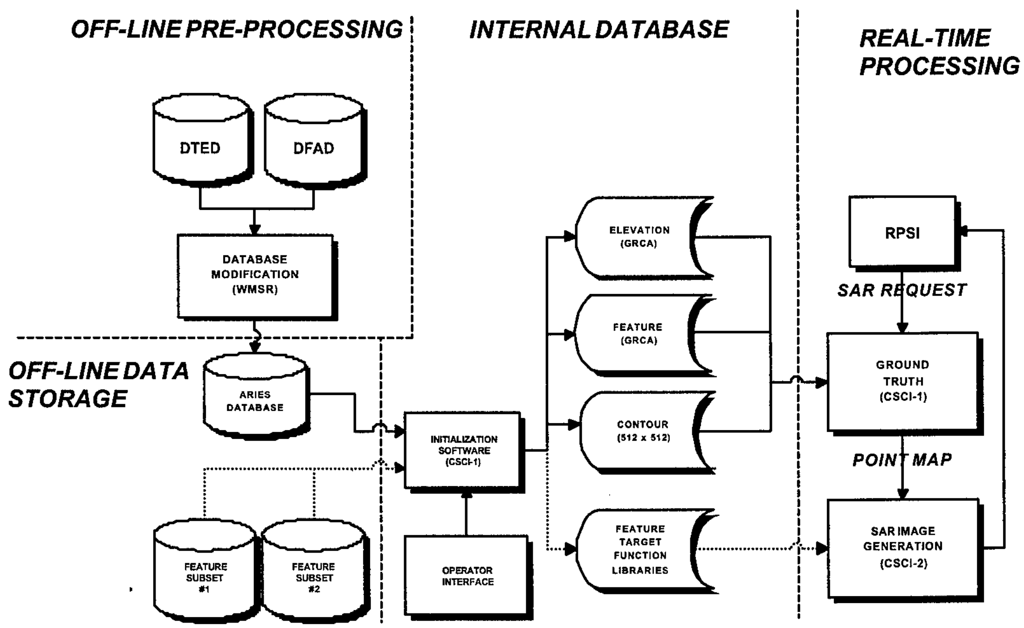
2.1 Technical Approach

As mentioned previously, ARIES was developed in three successive builds. The following sections define the builds and the functionality attained with each one.

2.1.1 Build 1

Build 1 demonstrated the functionality of the shaded modules and solid line interfaces in Figure 2.1-1.

Figure 2.1-1 ARIES system design illustrating modules associated with Build 1.



The shaded modules and solid lines indicate the software and interfaces that are functional with this build.

The Off-line Pre-Processing Module converts the DTED and DFAD data to the ARIES database as defined in the Digital Database ICD. This conversion work was performed by the government and provided as GFE. As ARIES is executed in conjunction with other simulations in the RPSI, a common database origin must be matched for registry of images. This conversion process converts the latitude/longitude coordinates of the DMA databases into the agreed upon "topocentric" coordinates of the simulation arena. No other database manipulation is performed. The ARIES database contains a 512 km x 512 km "playing field" and is stored off-line on a tape.

The Internal Database Module consists of the intialization software which handles the loading of the databases into memory consistent with an operator chosen subset of the entire 512 km x 512 km arena. Upon system startup, the initialization software will execute an initialization file which contains the Ground Reference Coverage Area (GRCA) parameters (location, width, depth), and season, atmosphere, and wind conditions. These parameters are specific to the execution of the simulations up to the time they are changed (reinitialized). These parameters are changed through an operator interface

to the initialization file and may be modified at any time to meet the mission requirements as needed. Based on the GRCA parameters set by the operator, the initialization software retrieves the elevation and feature information from the external tape and loads it into memory for quick retrieval during executions.

The Real-Time Processing module includes an RPSI interface and the software image generation modules, CSCI-1 Ground Truth and CSCI-2 SAR Image Generation. The RPSI interface provides all operational and navigational parameters for SAR processing and, in turn, accepts a SAR image upon completion. This interface was tested during Build 1 and can pass and accept all radar parameters and images as specified in the RPSI ICD. CSCI-1 directly interfaces with the RPSI, and upon receiving a SAR image request, it accepts and parses the operational and navigational data received. This message contains the Area of Interest (AOI), sensor parameters, and target type, state, orientation, and location. To test CSCI-1 functionality during Build 1, a routine was invoked that displayed targets by placing a symbol in their respective locations in an image. This image did not contain any SAR information at that time, and was used for target placement and I/O verification. The image was then passed to CSCI-2 which, in turn, sent the image back to the RPSI, verifying the interface functionality between the RPSI and CSCI-2.

Build 1 consisted of the delivery of the first draft elevation and feature database modifications from WSMR, the initialization software, and all software necessary to integrate and test system and software interfaces.

2.1.2 Build 2

Build 2 demonstrated the functionality of the shaded modules and solid line interfaces in Figure 2.1-2.

Build 2 provided a preliminary SAR output image. The simulation software generates an image that contained a subset of the required features and targets. The SAR image is based on feature data contained in the GRCA. Targets, previously designated by symbols in Build 1, have their SAR signatures inserted into the imagery. Build 2 utilizes portions of CSCI-1 Ground Truth, with the added capability from CSCI-2 SAR Image Generation, to produce the preliminary SAR output image.Build 2 utilizes the development of support libraries, required for ARIES SAR image emulation, as identified in Figure 2.1-2. The ARIES library contains the SAR representation of selected terrain textures, manmade and cultural features, target signatures, and tabulated mathematical functions. These allows efficient look-up of tabulated data rather than time-consuming calculations where real-time performance is mandatory. Terrain textures include features such as gravel, sand, and rocky flats. Manmade features include buildings, oil storage tanks, and power lines. Terrain textures and features are based on sample JSTARS imagery, when available and are used in the testing activity at the program end. XPATCH Target signatures were not deemed necessary due to the resolution of the JSTARS sensor. Targets were extracted from real imagery and based on their spatial distribution, were recreated to emulate real signatures for use in ARIES. Function libraries are used for mathematical efficiency and include tabular functions and precomputed weighting factors used in image processing.

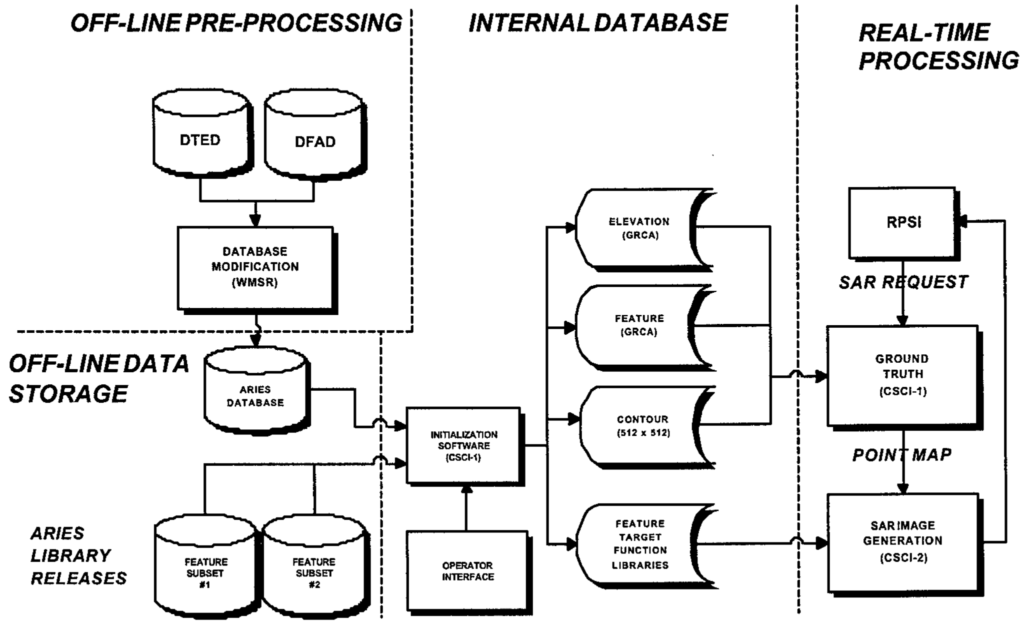


Figure 2.1-2 ARIES system design illustrating Build 2 completed modules. All interfaces between modules are working and the first subset of the ARIES library has been released.

CSCI-1 generates a ground truth for the SAR scene. This ground truth is a point map for locating features and targets in the image, and contains all elevation data necessary for the 3-D processing effects that are performed in CSCI-2. In this build, CSCI-1 loads the GRCA elevation and feature data and rotates it into the line-of-sight. The elevation data, previously stored at low resolution, will be upsampled to the sensor resolution. All the CSCI-1 processed data is stored in a structure referred to as a point map and is passed to CSCI-2 for SAR processing.

CSCI-2 accepts the point map generated in CSCI-1 and performs a 3-D to 2-D projection. The height parameter on the 3-D topographical and feature data is used to generate obscuration, shadows, and surface gain reflectivity. This parameter calculates edge reflectivity effects due to the dihedral geometry created by two adjacent surfaces of differing heights. The gain is a function of surface geometry and material parameter. Once the gain and shadow map is complete, the SAR targets, textures, and features are inserted into the image. The textures and features are modulated by the gain map, thereby ensuring that features are not inserted where there is obscuration or shadowing. Moving targets are inserted last in the image, as their velocity affects location and signature. The combined gain map and features produce an image referred to here as a "raw" SAR image, ie., this image has had only geometric processing performed on it. The final step to simulation is applying image processing on the raw image. The insertion of features and textures requires the blending of edges, seams, and boundaries. This process requires a filtering procedure to spatially correlate each feature to another.

2.1.3 Build 3

Build 3 demonstrated the functionality of the shaded modules and solid line interfaces in Figure 2.1-3.

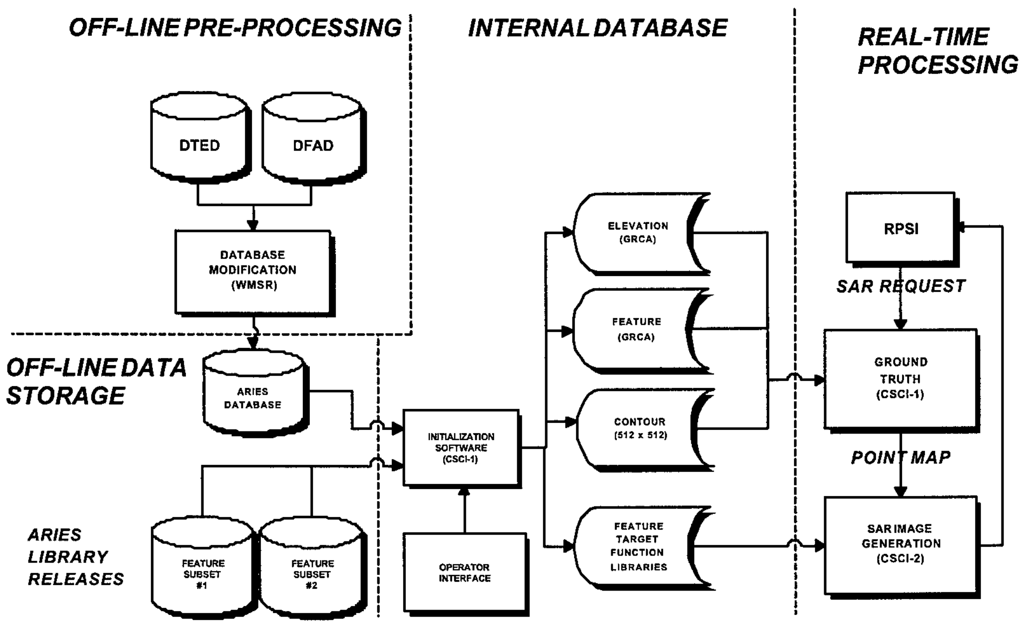


Figure 2.1-3. ARIES system design illustrating completed modules.
The complete set of features have been integrated into the library and CSCI-1 and CSCI-2 are fully functional having complete image processing capability.

Build 3 produces the complete ARIES SAR image generation capability. Build 3 integrates the completed CSCI-1 and CSCI-2, and the full set of features supported by ARIES. Acceptance testing at the completion of this effort was conducted to verify conformance with the Software Requirement Specifications and the customer submitted Acceptance Test Procedure. Results of those tests are in the Acceptance Test Section 5.0.

3. Software Design

3.1 Software Architecture

As ARIES was implemented in a prototype development environment, the design was revised as implementation progressed. The new ARIES software architecture is best represented as four distinct modules: Initialization, Ground Truth, SAR Generation, and Support. Initialization and Ground Truth comprise CSCI-1 and SAR Generation and Support comprise CSCI-2. Table 3.1-1 represents the software structure, module file names, and functional description. Execution begins when the Initialization module is called to setup the memory structures required for execution. The Ground Truth module provides the entry point for the real-time image generation software. The SAR Generation module is invoked by the Ground Truth module which then returns the image and status to the calling routine. Execution within the CSCI, through the CSUs, is basically a linear procedure as listed in Table 3.1-1. Each CSCI main module contains initialization entry points called by the Initialization module.

Table 3.1-1 Software Structure, Module File Names, and Functional Descriptions

CSCI / CSC / CSU	Module Name	Description
Initialization (CSCI-1)	init_main	Upper level control. Read elevation data, crop to GRCA.
Read .INI	init_ini	Read aries.ini file and parse parameters.
Read Features	init_feature	Read feature data file and crop to GRCA.
Build Search Tree	init_tree	Create empty search tree structure.
Merge Features and Tree	init_merge	Parse features in to search tree.
Ground Truth (CSCI-1)	grnd_main	Initialize structures. Upper level control flow.
Setup Calculations	grnd_setup	Extract RPSI data and initialize parameters.
Transform Targets	grnd_targets	Transform target data to AOI coordinate system.
Extract AOI Features	grnd_feature	Extract feature data that is contained within the AOI.
Process Elevation Data	grnd_elev	Extract and interpolate AOI elevation data.
Create Ground Truth	grnd_truth	Draw AOI features into point map.
Draw Point & Linear Features	grnd_line	Draw point and linear feature types.
Draw Area Features	grnd_area	Draw area feature types.
SAR Generation (CSCI-2)	sargen_main	Read library. Upper level control flow.
Elevation Textures	sargen_fractal	Apply dune and fractal elevation textures.
Shadow Projection	sargen_shadow	Project shadows onto shadow mask.
Reflective Gain	sargen_gain	Compute gain returns for each point.
Texture Application	sargen_texture	Apply textures to image combined with gain.
Target Insertion	sargen_targets	Insert target chips and smears into image.
Image Processing	sargen_image	Apply filtering algorithms.
Noise Processing	sargen_noise	Apply noise and shadow mask.
Image Output	sargen_output	Convert complex image to pixel output.
Support (CSCI-2)	none	n/a
Common Functions	supp_funcs	Common support functions.
Data Logging	supp_logging	Debug data logging utilities.
Complex Numbers	supp_complex	Complex number operations for C.

3.2 Supported Features

Table 3.2-1 lists all features supported by ARIES and how those features are implemented.

Table 3.2-1 Features Supported by ARIES

Description	FID	Type	Ground Truth Implementation	SAR Image Implementation
Dual hiways with medians	250	Linear	Dual Line, width, elevation of -0.01m	Dark
All Weather, Hard Surface highway	251, 252, 255	Linear	Line, width, elevation of -0.01m	Dark
Fair Weather, loose or light surface road	253	Linear	Line, width, elevation of -0.01m	Dark
Cart track, trail	254	Linear	Line, width, elevation of -0.01m	Dark
Airport Runway and Taxiways	706	Linear	Line, width, elevation of -0.01m	Dark
Storage Tanks – General	801	Point	Single Point	Chip w/o profile
Soil	902	Area	Fill	Smooth
Sand dunes	907	Area	Fill with dune elevation texture	Smooth
Smooth, solid rock	910	Area	Fill	Fine
Rocky, rough surface	912	Area	Fill	Course
Dry Lake	913	Area	Fill	Smooth
Cleared ways	916	Linear	Line, width, elevation of -0.01m	Smooth
Walls	922	Linear	Line, width, edge, fill, elevation	Dark/Smooth
Fresh water	940	Linear/Area	Line+width or Area, elevation of -0.2m	Dark
Canal	947	Linear	Line+width, elevation	Dark
Non-perennial stream	945	Linear/Area	Line+width or Area, elevation	Dark
Depot	778	Area	Fill	Smooth
Packed sand & gravel	906	Area	Fill	Fine
Loose Sand	917	Area	Fill	Smooth
Dry Depression	918	Area	Fill	Smooth
Wadi	919	Linear/Area	Line+width or Area, elevation	Smooth
Salt Marsh	908	Area	Fill	Dark
Salt Flats	934	Area	Fill	Fine
Flood Plain	914	Area	Fill	Dark
Power Trnsmssn Twrs	540	Point	Single Point, elevation (lines between)	Chip w/o profile
Electric Power Lines	541-544	Point/Linear	Line, one point wide	Impulse
Communications Twrs	501	Point	Single Point, elevation	Chip w/o profile
Date Palm	957	Point	Single Point	Chip w/ profile
Revetment - Soil/sand/dirt	981	Linear	Line, width, elevation	Fine
Levee	921	Linear	Line, width, elevation	Fine
Berms	982	Linear	Line, width, elevation	Fine
Escarpment	924	Linear	Line, width, elevation	Smooth

Table 3.2-1 Features Supported by ARIES (cont.)

Description	FID	Type	Ground Truth Implementation	SAR Image Implementation
Chain link Fence	927	Linear	Line, one point wide	Impulse
Barbed wire Fence	983	Linear	Line, one point wide	Impulse
Concertina Fence	984	Linear	Line, one point wide	Impulse
Irrigated Field	958	Area	Fill	Dark
Ditch	985	Linear	Line, width, elevation	Fine
Trench	986	Linear	Line, width, elevation	Fine
Oil Wells	103, 474	Point	Single Point, elevation	Chip w/o profile
Palm Tree	551	Point	Single Point	Chip w/ profile
All Buildings	104, 120, 130, 138, 160, 180, 181, 182, 184, 222, 290, 301, 324, 401, 420, 430, 451, 530, 601, 604, 620, 630, 650, 680, 701, 770, 822, 824, 861	Point	Building, edge, fill, elevation	Dark/Smooth
Pipelines	281	Linear	Line, one point wide, Orientation	Impulse
Railroad tracks	206	Linear	Line, one point wide, Orientation	Impulse
Quarries	102	Area	Fill	Course
Bridges	260	Point	Length, Width, fill, Elevation of corner	Impulse

3.3 Supported Targets

The following list represents the targets supported by ARIES for VSTARS

ARMORED PERSONNEL CARRIERS - WHEELED

BRDM-1

BRDM-2

BTR-60P

ARMORED PERSONNEL CARRIERS - TRACKED

BMP-2

BMP-1

MTLB

TRUCKS

M-35

HMMWV

M-49A2C

UAZ Jeep

AA GUNS

ZSU-23-4

SA-13

Long Track Radar

TOWED GUNS

D-30

T-12

MULTIPLE ROCKET LAUNCHERS

BM-21

BM-22

TANKS

T-54

T-55-T-72

SELF PROPELLED GUNS

2S1

2S2

HELICOPTERS

MI-8 HIP

MI-24 HIND

M-28 HAVOC

TELS

SA-6

4. System Performance

4.1 Objectives

4.1.1 Database Driven

The objective of the ARIES simulation tool is to model a JSTARS SAR sensor in a which the image content directly correlates with the real world, and the operational and navigational parameters implemented in the simulation are those of an actual aircraft during data collection. To model the real world, also referred to here as ground truth, a terrain database is needed to describe the surface topology and a feature database is required that describes the features that lie within the terrain.

The databases that were implemented for ARIES were DMAs DTED Level I and DFAD. The terrain database has a significantly courser resolution than the SAR sensor as DTED Level I consists of 100-meter elevation posts. For a typical SAR image, this equates to approximately 20 elevation posts used to describe the ground in cross range and 40 elevation posts used to describe the ground in range. Because as the SAR sensor has a much finer resolution, this creates a major discrepancy between the ground truth description and and the amount of detail the virtual SAR needs to create a realistic image. ARIES handles this problem by first performing an interpolation in both directions using the real elevation data and, secondly, overlaying a finer elevation grid that is representative of the terrain type on which the image is being created. As an example, a mountainous terrain would have a largely varying elevation grid applied and, likewise, a desert terrain would call for a smoother and finer elevation grid. This methodology brought a visual reality to the images that was not evident when just using DTED alone. Does this accurately represent the real world to the resolution of the sensor? – only as a first approximation, but no database exists at this time that does. Because no images were provided of Southwest Asia at the operational parameters of the VSTARS system, the “look” of the terrain is a subjective matter, largely based on the imagination of the developer.

4.1.2Real-Time Processing

A requirement was placed on the ARIES simulation to produce an image in real time which is defined as the time for the real sensor to collect and process data. The real-time processing was to be performed on a DEC Alpha 600 single processor that has one Gigabyte of RAM. Originally the display image size was given by Northrop Grumman to be 1024 pixels x 512 pixels. This image display was increased as more information was provided throughout the design process to a final image size of 1632 x 1024. The image dimensions had grown by a factor of four (we process internally to a power of two thus creating a 2048 x 1024 image , then cropping to the required 1632 x 1024) but the image generation timeline had only increased by a factor of 1.8 – acceptable with respect to the requirements. The timeline, had the image size remained the original, would have been satisfied with seconds to spare. The real-time image generation issue guided the majority of the ARIES design. Much of what could have been processed or generated during execution was skillfully created ahead of time and implemented using tabular data and libraries.

4.1.3 Image Quality

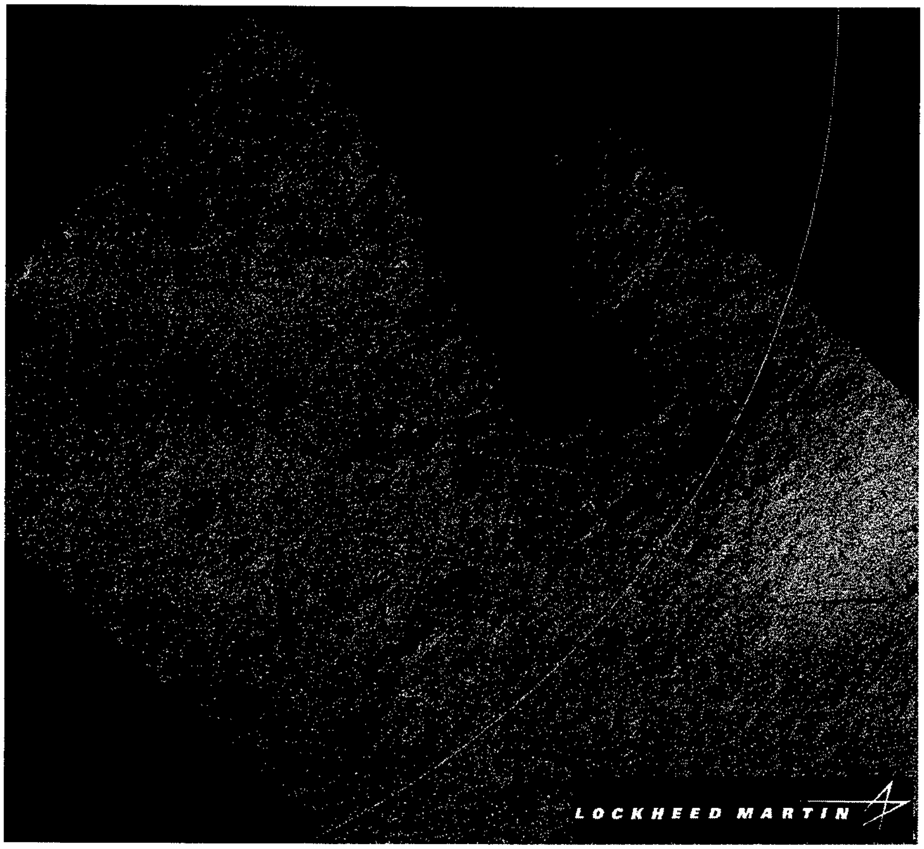
The performance of the ARIES system is measured against the performance of the real JSTARS SAR sensor. It is the objective of the simulation to emulate the effects of a real SAR sensor, not that of a real processor. Much of the SAR effects that are visible in radar images are due to the physical attributes of the terrain and features that are illuminated. Other factors include the electromagnetic scattering properties of the features, the operational parameters of the sensor, the navigational parameters of the aircraft, and the image processing techniques used to visually optomize the images. To evaluate all these factors and their effects on the images, real imagery was requested from Northrop Grumman that would be used as a sample for development purposes. It was necessary to provide images that contained the same type of operational and environmental conditions as would be present in the VSTARS simulated scenarios. The following paragraphs describes the images provided by Northrop Grumman and the VSTARS scene requirements that either did or did not match those of the sample images.

The terrain used for the VSTARS is in Southwest Asia, therefore it was imperative, as a minimum, that the sample imagery provided by Northrop Grumman be that of desert terrain. The radar operational parameters used to collect the data are also of significance in the example images, because the terrain and features varied dramatically under various depression angles, squint angles, aperture times, and ranges. It was for this reason that Lockheed Martin TDS Arizona requested the complex data output of the real processor. This data would have provided the necessary absolute values on dynamic range, target-to-clutter ratio, and background noise levels. The complex data was not provided and, therefore, the simulation development largely comprised analyzing the intensity and spatial distribution of byte scaled, histogram equalized images.

Most visual evaluations performed after final system integration on the background terrain gave positive feedback. Most evaluators asked if the images were simulated or real – which proved to be the best compliment to the realism. Two evaluators differed greatly on their assessment of what was "wrong" with the background. One evaluator thought the terrain was too sharp and thereby created too much contrast in the image. Another evaluator thought that there was not enough contrast and the background needed much larger hills and valleys. The conclusion made by Lockheed Martin TDS and the customer - without the proper data supplied by Northrop Grumman to support these image evaluations and their subjective content, the quality and realism are left to the individual viewer. The image quality was deemed acceptable by the customer's requirements.

4.2 Sample Imagery

The following section contains simulated imagery that was processed through the RPSI following the final installation at Northrop Grumman.



To initiate the virtual SAR, a Radar Service Request (RSR) is obtained from an operator interface. The area to image is chosen by viewing the hyposographic data on the operator workstation, clicking in on the earth coordinates that lie within the radar coverage area, and initiating an RSR. This interface is a mock-up that the operator uses on the aircraft workstations. Moving and stationary targets are supported by passing target information from a DIS link through the RPSI and parsing it to ARIES via a target file. This file contains the reference information required to locate and process targets within the SAR image. The hypsographic data is overlayed onto the images and is evident by the lines passing through or outlining some of the features.

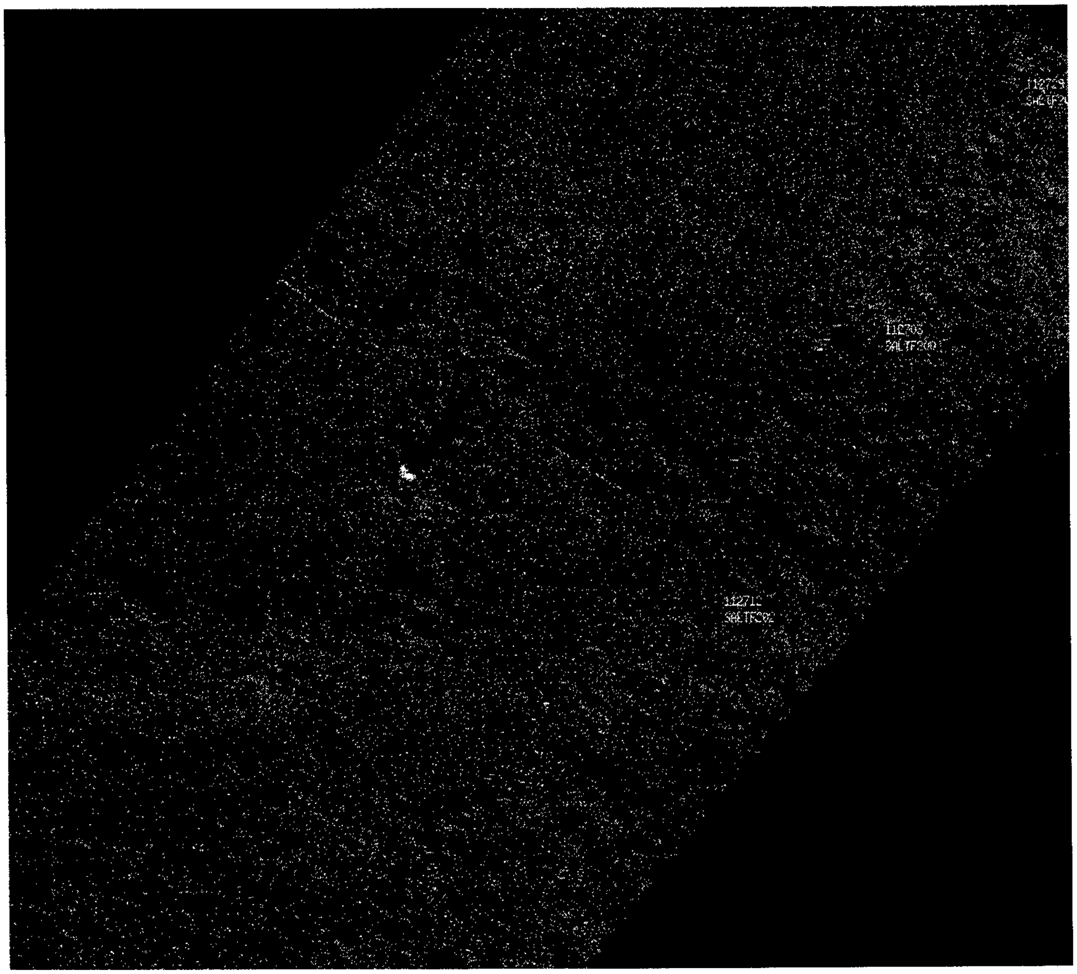
This image represents several successive merged data collections. The features present in these collections are a road traveling NW to SE as well as several rivers meadering through the image. The roads and rivers are represented by the hypsographic overlay. The lines and features are slightly offset due to Circular Error Probability (CEP) applied to each SAR image.

This simulated image is data collected over a dune region.

This simulated image is several successive data collections merged together for display purposes. The dark feature that forks is a river bed. The hypsographic overlay displays the ground truth for all the offset example cultural features present image. Grey lines follow the roadways. CEP is evident in the registration of the last image with the previous one.

This image is an example of background terrain with a road running SW to NE. The granularity and variation of the background are due to the low grazing angle that the sensor operates at. At these angles, the smallest changes in the earth's surface produce high contrast variation in the image.

This image contains a river bed, concrete levy, bridge, buildings, and a road. The large building viewed above the river is a representation created from DFAD data that is not accurate enough to adequately describe the structure. Many DFAD buildings are described as omnidirectional and extremely large. They are, in actuality, a complex of many buildings all having various heights and orientations. The government will be "fixing" DFAD to better describe these type of structures. ARIES relies on the database to be correct for accurate representation.



This image represents a salt flat feature. The courseness of the surrounding terrain next to the salt flat is evident by the high contrast variation viewed in the image. The smoother, finer areas represent the actual salt flat. The flats themselves are geometric in shape and were probably man-made along the edges. A road is evident running through the center of the image, as is a building that appears as a bright specular response in the center.

5. Factory Acceptance Testing

A test suite of images has been established as the baseline regression and factory acceptance test for the ARIES product. Each ARIES requirement is mapped to at least one test image which demonstrates ARIES ability to support that requirement. Additional test cases are provided to validate system performance and accuracy.

5.1 Requirements versus Test Cases

Table 5.1-1 defines all ARIES requirements and maps each to a test case. The test cases are described in the table that follows. All test cases have been run and the images, FID (Feature Identification) maps, shadow maps, gain maps (based on geometry and reflectivity of the surface) and other output information examined to verify accuracy.

Table 5.1-1 ARIES Requirements

Req #	Test #	Requirements
100	1	ARIES will simulate a JSTARS SAR image in real-time on a DEC Alpha 600/533 workstation as specified in the Classified Appendix
110	2	ARIES shall implement an earth curvature corrected coordinate system.
120	3	ARIES shall simulate a fixed image size with dimensions of 2 km x 4 km.
130	3	ARIES shall simulate an image with constant resolution in range and azimuth.
140	4	ARIES shall simulate images in the slant plane.
150	4	ARIES shall generate a magnitude simulated image.
160	4	ARIES shall simulate leading edge effects.
170		ARIES shall simulate the effects of range layover.
190	2	ARIES shall simulate the effects of obscuration along the sensor line-of-sight.
200	4	ARIES shall simulate a single look capability.
210	4	ARIES shall simulate a focused Spot SAR.
220	4	ARIES shall simulate depression angles up to 12 degrees relative to horizon.
230	4	ARIES shall simulate a maximum squint angle of +/- 60 degrees off broadside.
240		ARIES shall simulate summer seasonal conditions.
250		ARIES shall simulate clear atmospheric conditions.
260	6	ARIES shall simulate calm wind conditions.
270	4	ARIES shall simulate SAR imagery in accordance with JSTARS sensor performance parameters.
280	4	ARIES shall simulate X-band.
290	4	ARIES shall simulate HH polarization.

300	3	ARIES shall simulate a single resolution in range and azimuth as specified in the classified appendix.
320	2	ARIES shall use an elevation database for simulating topographical effects within a simulated image.
325	8	ARIES shall support an elevation database which encompasses an area up to 512 km x 512 km.
330	4	ARIES shall use a feature database to locate natural and cultural features within a simulated image.
340	2	ARIES shall accept earth curvature corrected elevation data from the GFE database.
350	2	ARIES shall accept earth curvature corrected feature data from the GFE database.
360	4	ARIES shall accept point feature data.
370	4	ARIES shall accept linear feature data.
380	26	ARIES shall accept areal feature data.
390	n/a	ARIES shall incorporate effects of features and topography which lie outside of Area of Interest (AOI) that influence obscuration within the AOI.
420	8	Rocky flats (maximum boulder size of 1 foot)
430	9	Packed sand and gravel
440	4	Loose sand
450	10	Windblown dunes
460	11	Dry depressions with sandy bottoms
470	12	Wadis
480	13	Escarpments
490	14	Salt marshes
500	15	Salt flats
510	16	Flood Plains
520	4	Date palm orchards
530	17	Irrigated fields
540	4	Buildings
550	4	Cylindrical storage tanks
560	4	Oil wells
570	2	Above ground pipelines
580	18	Soil/sand/dirt berms referred to as revetments
590	19	Below ground sand/dirt trenches
600	4	Above ground concrete and dirt bunkers
610	19	Sand/dirt ditches
620	4	Paved roads
630	20	Unpaved roads
640	21	Loose dirt trails (less than 1 road width)
650	2	Railroad tracks

660	4	Airfields - composed of buildings and runways
670	4	Transmission towers - 4 sided pyramidal
680	4	Electric power lines
690	22	Dirt and concrete dikes and levees
700	23	Dirt and concrete walls and berms
710	19	Anti-tank ditches
720	2	Pipelines within trenches
730	24	Quarries
740	2	Chain link fences
750	2	Concertina fences
760	2	Barbed wire fences
770	2	Bridges
800	4	ARIES shall simulate moving targets.
810	4	ARIES shall simulate stationary targets.
830	4	Tanks, ie. T-72, T-72 w/plow, T-72 w/mine roller, T-54/55
840	4	Air Defense Systems, ie. Long Track Radar, MTLB, ZSU-23-4
850	4	Armored Personal Carrier, ie. BMP-1, BMP-2, MTLB
860	4	Artillery, i.e. 2S1, 2S3
870	4	Armored Cars, ie. BRDM w/machine guns, BRDM w/AT-5s, BTR-60, BTR w/120mm mortars.
880	4	Artillery, i.e. BM-21, BM-22, D-30, T-12
890	4	Support Trucks, i.e. UAZ-469, 5-Ton CAC, 5-ton fuel, 2 ½-ton cargo
900	4	MI-24
910	4	MI-8 Hip
920	4	HAVOC
930	4	ARIES shall support TEL targets.
940	b2.1	ARIES shall simulate SAR imagery in accordance with data provided through an interface with Northrop Grumman's RPSI as specified in the ARIES-RPSI Interface Control Document.
950	b2.1	All coordinates passed to ARIES through the RPSI shall be relative to a topocentric coordinate.
960	b2.1	Area of Interest Centeroid (x,y,z) (m)
970	b2.1	Resolution (m)
980	b2.1	Wavelength (m)
990	b2.1	Dwell Time (s)
1000	b2.1	Azimuth extent (radians)
1010	b2.1	Range extent (m)
1020	b2.1	Sensor position (x,y,z) (m)
1030	b2.1	Sensor velocity vector (m/s)
1040	b2.1	Antenna orientation vector
1050	b2.1	Number of targets within image
1060	b2.1	For each target in the image area, Target category, ie. tank, truck, launcher

1070	b2.1	For each target in the image area, Target subcategory, ie. M-1, M-60
1080	b2.1	For each target in the image area, Target specifics
1090	b2.1	For each target in the image area, Target position centroid (x,y,z) (m)
1100	b2.1	For each target in the image area, Target velocity vector (m)
1110	b2.1	For each target in the image area, Target orientation vector
1120		For each target in the image area, target appearance
1170	b2.1	ARIES software shall execute on the Alpha 600 5/333 workstation.
1180	b2.1	LM shall have 1GB of RAM on the Alpha 600 5/333 dedicated to ARIES during simulation activity.
1190	b2.1	ARIES executable software and resident operating system shall have access to 100% of the processing resource CPU time on the Alpha 600 5/333 during simulation activity.
1200	1	ARIES software shall execute under OpenVMS, version 6.2 or later.
1210	b2.1	ARIES software shall be compatible with the RPSI environment.
1220		ARIES software shall return a pass status upon successful completion of image generation.
1230	b2.1	ARIES software shall return a fail status upon unsucessful completion of image generation.
1260	b2.1	ARIES shall pass image data to the RPSI with 2000/R pixels in cross-range by 4000/R pixels in range where R is the resolution parameters in meters passed by the RPSI.
1300	b2.1	ARIES software shall accept a Ground Reference Coverage Area (GRCA) as input from the RPSI as specified in the ARIES - RPSI Interface Control Document.
1310	b2.1	ARIES shall simulate an image which is completely encompassed by the GRCA boundaries.

5.2 Test Cases Defined

Tables 5.2-1 defines the test cases and describes what each test case involves.

Table 5.2-1 Test Care Description

Test #	Title	Description
1	Alpha Execution	Run alpha test program on both the SUN and the alpha with default values to generate an image output file. Verify the image from the alpha matches the same image generated on the SUN. This image is generated using the small library, small DFAD and small GRCA.

2	Terrain / Shadow / Feature Verfication	Output is the shadow map from 8 different angles of the same terrain. Print and align the maps to verify terrain matches in all. AOI is at 0, 0. Final image contains artificial features used for quality verification. These image contains a feature of known height in known terrain at known depression angles. Verify shadow length.
3	Resolution Distortion	Compare with test #2 for different resolution in X and Y.
4	General Image Quality	Generate airport scene and verify image quality of contained features. Print out feature maps and align to verify constant location of features. Image contains all target types and moving targets.
5	Terrain / Feature Matching	Print the gain and the feature maps and overlay to verify match between the two.
6	Windy	Run only the first few images and compare the windy palm trees with the calm palm trees in test 4.
7	GRCA Test	Different sizes and shapes of GRCA's in different ARIES of the database. Verify features and terrain.
8	Coarse + Smooth Textures + Stream + Mnt.	Image shows the coarse texture contained within the smooth texture background.
9	Fine + Smooth Textures	Image shows the fine texture contained within the smooth texture background.
10	Dunes + Smooth	Image shows an area of sand dunes within the smooth texture background.
11	Dry Depression	Sample image of feature and other missing items
12	Wadi	See test 11
13	Escarpments	Sample image of feature
14	Salt Marshes	Sample image of feature
15	Salt flats + Pipeline	Sample image of feature
16	Flood Plains	Sample image of feature
17	Irrigated fields	See test 11
18	Soil/sand/dirt berms referred to as revetments	See test 11
19	Below ground sand/dirt trenches	See test 11
20	Unpaved roads + Ocean	Sample image of feature
21	Loose dirt trails (less than 1 road width) + Dry Lake	Sample image of feature
22	Dirt and concrete dikes and levees	Also includes orchards, power plants, telephone poles and wires and a real bridge!

23	Dirt and concrete walls and berms	Sample image of feature
24	Quarries	Sample image of feature
25	Divided Hiway	Sample image of feature
26	Area Features	This is a set of artificial area features designed to challenge the area feature routines. Print the FID maps and verify alignment.
27	Timing	Run a set of images on sarsim using a complete but reduced library to assess actual timing.
28	Odd angles	General test at odd angles, compare FID maps with those from test 4.
29	Linear	Test pattern of linear objects.
30	Runways	Dual runways
31	Orchards	Orchard areas.

5.3 Real Time Processing Predictions

Table 5.3-1 illustrates the allocated and projected image processing times. The projected execution at NG was 32.7 seconds. The actual execution time for the same image was 24 seconds. Execution time will vary depending on image contents. During build 3 delivery at NG reliable execution times as high as 30 seconds were noted. This is all still below the projected time.

Table 5.3-1 Allocated and Projected Image Processing Times

	Allocated	Timing Predictions		Actual Times			
CSC	%	Target Host Times Required	Sun Ultra 1 Timing Allocation based on Build 2 benchmark	Actual Timings on Sun Ultra 1	Predicted vs Actual Timing Differences on Sun Ultra 1	Predicted Host Execution Times based on Build 2 benchmark	%
		20.00	22.14	48.70	90%	44.00	
Process RPSI Data	0.00%	0.00	0.00		0.00	0.00	0.00%
External Obscuration	5.00%	1.00	1.11		1.11	0.00	0.00%
Transform AOI	5.00%	1.00	1.11		1.11	0.00	0.00%
Generate Point Map	25.00%	5.00	5.53	8.00	-2.47	7.23	22.11%
3D to 2D Projection	15.00%	3.00	3.32	2.00	1.32	1.81	5.53%
Chip & Texture	15.00%	3.00	3.32	7.00	-3.68	6.32	19.34%
Final Image Proc.	35.00%	7.00	7.75	15.47	-7.72	13.98	42.75%
Image Output	0.00%	0.00	0.00	3.72	-3.72	3.36	10.28%
Totals	100.00%	20.00	22.14	36.19	-14.05	32.70	100.00 %

Initialization		300.00	271.05

Table 5.3-2 uses the measured execution times from the SUN scaled to the original image size of 1024 x 512 pixels. The projected execution time here is well within the time allotment when processing this size of image.

Table 5.3-2 Measured Execution Time from SAR

CSC	Allocated %	Timing Predictions: Target Host Times Required	Timing Predictions: Sun Ultra 1 Timing Allocation based on Build 2 benchmark	Actual Times: Actual Timings on Sun Ultra 1	Actual Times: Predicted vs Actual Timing Differences on Sun Ultra 1	Actual Times: Predicted Host Execution Times based on Build 2 benchmark	%
		20.00	22.14	48.70	90%	44.00	
Process RPSI Data	0.00%	0.00	0.00		0.00	0.00	
External Obscuration	5.00%	1.00	1.11		1.11	0.00	
Transform AOI	5.00%	1.00	1.11		1.11	0.00	
Generate Point Map	25.00%	5.00	5.53	2.48	3.05	2.24	24.10%
3D to 2D Projection	15.00%	3.00	3.32	0.62	2.70	0.56	6.02%
Chip & Texture	15.00%	3.00	3.32	2.17	1.15	1.96	21.09%
Final Image Proc.	35.00%	7.00	7.75	3.87	3.88	3.49	37.58%
Image Output	0.00%	0.00	0.00	1.15	-1.15	1.04	11.21%
Totals	100.00%	20.00	22.14	10.29	11.85	9.30	100.00 %
Initialization				300.00		271.05	

6. Final Build Summary

ARIES final build was a great success. The customer indicated overwhelming satisfaction with the product and with the Lockheed Martin TDS-Arizona ARIES team members. The following paragraphs discuss the outcome of the software integration.

A software delivery was made to Northrop Grumman (NG) in June 97. This had constituted the "fixes" of Build 2. NG was given 10 days to integrate the software and inform LMTDS of a successful integration. Because no report was given on the status of the integration, LMTDS assumed all had gone well. It became evident two weeks prior to the last build (August 25) that NG had not integrated the Build 2 software fixes and was now encountering problems associated with trying to integrate it late in August.

During Build 2, there was still some integration issues that dealt with the resolution of the display images and how both LMTDS and NG would treat those displays. Because it was not known ahead of time what the display size is in azimuth from run to run, it was agreed that Lockheed Martin would always return the same size image. It was up to NG to crop the image as needed to match the display size required. NG attempted to fix the resolution issue without success. The images were appearing skewed

upon display at NG. Because this was not the case at LM, clearly, it was a display function that needed to be fixed in NG display routines. LM provided all the detail of our processing via telephone and e-mail, and informed NG exactly what needed to be done on their end to fix the problem. Weeks passed with no response. To resolve this issue, LM funded an unscheduled trip for David Corgan to go to NG and fix this and any other problems (some of which were unknown) that occured. LM realized that the display ratio problem was a matter of NG passing the azimuth width in radians of the final image size, not of the size that ARIES passes back to the RPSI.

While a number of items were identified for further analysis and possible future modifications, only one item was identified as a priority change. The target chips appeared too small to be visible on the NG display. Because they were deemed "too large" at LM the week prior, this was a surprising result. LM was also asked to remove the antenna "rolloff" function that made the image appear darker as a function of azimuth. Because the rolloff boosted the targets to be more visible, removing it made them fade into the background. LM analyzed the images on our own system and remade the targets. The appearance of the targets in the images will not be verified until a set of images is executed at NG and send to LM for analysis. The displays are slightly different and ultimate verification is made by viewing on the NG system.

NG had mentioned that the contrast ratio was not correct in the simulated images. NG offered the Signal-to-Noise ratio (SNR) as a "fix" to determing the proper contrast ratio. LM does not see the correlation between the value of the SNR and adjusting the contrast ratio based on this value. The contrast ratio between two areas of the image is a ratio of the image intensities in the two areas-not the signal-to-noise ratio. The contrast ratio of the simulated images matched that of the real images when measured on byte scaled data between shadow and flat terrain. The real images that were used as an example for the simulated images also were heavily attenuated due to a loss of antenna power across the image. Therefore, choosing an area that best described the area to emulate was a subjective matter. The contrast ratio of one area in the real data varied greatly from another. LM had requested the IQ data for each of the images. This would have provided the necessary absolute values of the clutter, targets, and noise that a single SNR value cannot provide. The images that LM were given were postprocessed through a weighted histogram equalization routine that distributed the byte scale detected data in a way that was unknown to LM. Therefore, going from this format to determining the IQ values would not be possible. The images were also provided without ground truth i.e., it was not known whether some of the targets were moving thereby appearing larger and brighter than normal.

The following items were software fixes that occurred during integration and test at NG.

1. CEP was divided by two to produce less error and be more characteristic of the system.

2. Target chips were scaled to be brighter by a factor of 20 upon initialization. This was rectified by increasing the size of the targets.

3. Antenna attenuation as function of azimuth was deleted.

4. New moving target response. The LM applied response did not visually match the processing that NG does for the real data, as no ground truth has been delivered with the example images. NG "fixed" the moving target response by applying a phase error in an omnidirectional way with no regard for the aircraft velocity direction relative to target motion. This is not an acceptable solution to LM for integration into ARIES and will be revisited at a later date. It is clearly NOT possible for the phase error to be omnidirectional. Phase errors due to uncompensated motion are visibly apparent in azimuth only.

5. Targets and texture chips were "inserted" into background, not added.

6. The elevation backgrounds were scaled down by a factor of 5 for dry lake beds and flat ground.

Although the customer had accepted the above fixes as the critical modifications that needed to be done, LM identified the following modifications to include into Build 3.

1. New Target chips implemented into library – remove scaling at initialization

2. CEP divided by two is implemented in library

3. Fix missing middle of runways

4. Revisit the antenna rolloff procedure and address the image intensity without this process.

5. Lower water level for more leading edge on shores

6. Implement smooth soil background on orchards

7. Verify possibility of missing target at end of list.

The following items were identified during Build 3 delivery for modification during the next ARIES phase.

1. Road beds for highways

2. Implement variable quad tree depth

3. GUI

4. External Obscuration

5. Shadow enhancements

6. Terrain elevation grid registered with GRCA

7. Move CSCI-1 tables to library

8. Enhanced testing display tool

9. Moving target response

APPENDIX F

Interface Control Document

for the

Ground Station Module

T-1 LAN Interface

of the

Radar Processor and Integrator

for

Joint STARS

DOCUMENT NO. JADS - ICD - 002
CODE IDENT: Q001
DATE: JANUARY 1997

INTERFACE CONTROL DOCUMENT FOR THE GROUND STATION MODULE T-1 LAN INTERFACE OF THE RADAR PROCESSOR AND INTEGRATOR FOR JOINT STARS

CONTRACT NO:

prepared for :
Joint Advanced Distributed Simulation
Joint Test Force

prepared by:
Northrop Grumman

TABLE OF CONTENTS

1. Scope

This document defines the contents of the messages to and from the Ground Station Module (GSM) over a T-1 LAN interface for incorporation into the RADAR Processor Simulator and Integrator (RPSI) on the Joint STARS platform.

1.1 Purpose

The purpose of this document is to define the interface requirements between Northrop Grumman and Motorola regarding the RPSI. The RPSI is being developed for the integration of Joint STARS into the Joint Advanced Distributed Simulation (JADS) environment.

1.2 Application

Interface requirements set forth in this document apply during the development and laboratory testing of the RPSI.

1.3 Definitions and Conventions

The following conventions were used to describe each message interface:

- High Level Message Elements

  a. Message Name.

  b. Brief functional description of the message.

- Characteristics (Intermediate message elements):

  a. Source, Destination, Via, Transmission rate, and Size.

  b. Word Number

  c. Word Signal Name: either contains the actual field name or a functional name that best describes the fields within each message.

  d. Units: describes the engineering units to be applied against the word being described.

  e. MIN/MAX Range: describes the valid minimum and maximum range of values. If a single number is used, the min./max. Range is constant. If a number is enclosed parenthetically, (N), the number is ± N. The minimum and maximum range are evenly divisible by the least significant bit (LSB). Words that are encoded will have a min/max supplied as N/A.

f. Least Significant Bit (LSB): The LSB is defined to be bit 00, illustrated as the rightmost bit of a word. The LSB value is the weighting (scale factor) of the LSB.

g. Type: this describes the FORTRAN data type that is applied to the word being described.

- Field Descriptions:

a. Word Number: being described.

b. Field name of field being described.

c. Engineering Units, as described in the message Characteristics Table. Units can be described as bit encoded, meaning a bit map is required to fully define the field. Units can also be described value encoded, meaning the numeric value of the field means something other than the numeric itself.

d. LSB (when applicable) is supplied describing the weighting of the least significant bit.

e. Min/Max Range (when applicable) is supplied to describe the valid minimum and maximum range of the feild being described.

- Other Nomenclature:

a. Spare Fields are noted in word pictures as "XX" fields. All spare fields are assumed to be zero.

b. Most Significant Bit (MSB): The most significant bit is defined to be bit 15, shown as the leftmost bit of the word.

c. Hexadecimal Representation: numbers represented in hexadecimal will be noted using a lower case "x". For example the hex number 0F will be shown as either '0F'x or 0Fx.

2. Referenced Documents

Document Number	Title	Date
C99ICDVA345	The Airborne Data Terminal (ADT) Surveillance and Control Datalink (SCDL) Producibility Program Joint Surveillance Target Attack Radar System (JOINT STARS)	06 January 1995

3. Message Definitions

This section will identify those messages which will be supported by the RPSI and the added header information necessary for transmission over the T-1 LAN interface. The LAN interface will be a Standard 802.3 LAN and shall use the UDP protocol.

3.1 Messages To ADT

The following paragraphs contain the messages normally sent to the ADT by the 1553 bus controller. These messages in the normal system operations are described in the referenced ICD.

3.2 Control Messages

These messages are normally sent to the ADT by the E-8 1553 Bus Host and in general control the timing and priority of downlinked messages. The messages are Control, Adaptive Control A, and Adaptive Control B they will not be transmitted over the LAN.

3.2.1 Downlink Data Header

A downlink message is data normally received by the ADT, via the 1553 Bus, to be transmitted on the SCDL. The word formats as modified for retransmission on the T-1 are as follows:

Donwlink Data Header

Message Name: Data Header
Source: RPSI
Destination: GSM
Xmit Rate: Asynchronous
Size: 29 Words

Word	Signal Name	Units	Range	Init value	LSB	Type
01	Message ID	ID	9100x	N/A	1	I*2
02	Message Type	Coded	N/A	N/A	N/A	I*2
03	GDT Address	Coded	N/A	N/A	N/A	I*2
04-29	Data	Coded	N/A	N/A	N/A	I*2

Word 1— JADS Message ID this word is the JADS message identification.

Word 2 – Bit 0-4 Message Type

Bit 5-11 Serial Number. The value 0 is not a valid serial number. This fact is used by the receiving GDT to distinguish a Downlink message from a relay message.

Word 3 – Bit 0 GDT Address

Bit 1-2 Identifies the packet type as follows:

00 = Report Packet
01 = Dwell Packet
10 = Object Packet
11 = Single Packet

Bit 3 is dependent upon the value of the Packet ID it is normally supplied by the ADT software and is defined as follows:

When Packet ID equals:

00 = Report Packet	Bit 3 set indicates an acknowledgment is required.
01 = Dwell Packet	Bit 3 has no significance
10 = Object Packet	Bit 3 set indicates last packet of message.
11 = Single Packet	Bit 3 set indicates an acknowledgment is required.

This BIT will not be simulated by the JADS T-1 LAN interface.

Bits 4-15 Utility Field. User defined by the message originator (operator) to provide information to the GSM 1553 Bus Host about the downlink message. The definition of the information contained in this field is dependant on the value of the Packet ID and can be used by the GSM operator to obtain the following information:

When Packet ID equals:

00 = Report Packet   Utility Field contains the total count of Dwell or Object Headers in the message.
01 = Dwell Packet   Utility Field contains the serial number for the Dwell Packet.
10 = Object Packet   Utility Field contains the serial number for the Object Packet.
11 = Single Packet   Utility Field may contain data.

Word 4-29 Data

Bit 0-15 Data.

3.2.2 Aircraft Location

The Aircraft Location is a bus message containing the Latitude, Longitude, Altitude of the aircraft, the time delay and the current attitude of the aircraft in roll and pitch. The word formats as modified for retransmission on the T-1 are as follows:

Aircraft Location
Message Name: Aircraft Location
Source: RPSI
Destination: GSM
Xmit Rate: Asynchronous
Size: 9 Words

Word	Signal Name	Units	Range	Init value	LSB	Type
01	Message ID	ID	9200x	N/A	1	I*2
02	Latitude MSB	DEG	0-90	N/A	$8.32x10^{-8}$	I*2
03	Latitude LSB	DEG	0-90	N/A	$8.32x10^{-8}$	I*2
04	Longitude MSB	DEG	0 - 180	N/A	$8.32x10^{-8}$	I*2
05	Longitude LSB	DEG	0 - 180	N/A	$8.32x10^{-8}$	I*2
06	Altitude	Meters	32767.5	N/A	.5	I*2
07	Time Delay	msec	2550	N/A	10	I*2
08	Aircraft Roll	DEG	255.5	N/A	.5	I*2
09	Aircraft Pitch	DEG	255.5	N/A	.5	I*2

Word 1— JADS Message ID this word is the JADS message identification.

Word 2 – Bit 0 Sign of Latitude. 0 = North, 1 = South.

Bit 1 - 15, 15 Most Significant Bits of the aircraft latitude. (Note: the ADT truncates the data, using only the 6 MSBs of this word before downlinking to the GDT)

Word 3 – Bit 0-15 Latitude, 16 Least Significant Bits of the aircraft latitude.

Word 4 – Bit 0 Sign of Longitude. 0 = East, 1 = West.
Bit 1 - 15, 15 Most Significant Bits of the aircraft longitude. (Note: the ADT truncates the data, using only the 6 MSBs of this word before downlinking to the GDT)

Word 5 – Bit 0-15 Longitude, 16 Least Significant Bits of the aircraft longitude

Word 6 – Bit 0-15 Altitude, Aircraft Altitude. (Note: The ADT truncates the data using only the 12 MSBs of this word before downlinking to the GDT).

Word 7 – Bit 0-7 Spare
Bit 8-15 Time Delay, the delay from the aircraft position measurement to its transmittal on the 1553 Bus to the ADT.

Word 8 – Bit 0-6 Spare
Bit 7-15 Aircraft Roll Angle, absolute value of roll angle.

Word 9 – Bit 0-6 Spare
Bit 7-15 Aircraft Pitch Angle, absolute value of pitch angle.

3.2.3 Polling Control

The polling control is sent to the ADT by the E-8 to establish the polling sequence (uplink channel assignment). The polling control message will not be transmitted on the T-1.

3.3 Messages From The ADT

This section contains those messages normally transmitted by the ADT to the Bus Host via the 1553 data bus.

3.3.1 Transmit Vector Words

A message responding to a poll for uplink and relay data available from the ADT since last poll. This message will not be used for the T-1 LAN implementation.

3.3.2 Uplink Data Header

An Uplink Message is data normally received on the SCDL by the ADT. This message will received from the GSM via the T-1 LAN interface and processed by the RPSI. The format is as shown:

Uplink Data Header
Message Name: Uplink Data Header
Source: GSM
Destination: RPSI
Xmit Rate: Asynchronous
Size: 29 Words

Word	Signal Name	Units	Range	Init value	LSB	Type
01	Message ID	ID	9300x	N/A	1	I*2
02	Signal Strength	Coded	N/A	N/A	N/A	I*2
03	H Fields	Coded	N/A	N/A	N/A	I*2
04	Message Info	Coded	N/A	N/A	N/A	I*2
05-28	Data	Coded	N/A	N/A	N/A	I*2
29	Message Length	Coded	N/A	N/A	N/A	I*2

Word 1— JADS Message ID this word is the JADS message identification.

Word 2 – Bit 0 -7 Signal Strength. Not used in JADS
Bit 8 - 15 Signal Quality. Not used in JADS

Word 3— Bit 0 - 4 H Fields, are set by the ADT's receiver hardware to provide information on the uplink message. Not used in JADS.
Bit 5-15 Identifier, set to "1" to indicate an Uplink message.

Word 4 – Bit 0-3 Data, first four bits of the message.
Bit 4-8 Sender Address, valid addresses are 16,26, or 21 for an uplink. If monitor all uplinks bit is set addresses 1 through 15 are also valid (relay messages).
Bit 14-15 message Code, designates the function of the message as follows:

00 = No acknowledgment Required.
01 = Acknowledgment Required.
10 = Acknowledgment to Downlink packet or Relay message.
11 = Uplink acquisition message.

Bit 14-15 will not be used in JADS.

Word 5-28 – Data.

Word 29 – Long Message

Bit 0-2 Number of ACK Tries. Not used in JADS.
Bit 3 Data Length, ignored by the ADT. Not used in JADS.
Bit 4-15 Data.

Short Message

Bit 0-2 Number of ACK Tries. Not used in JADS.
Bit 3 Data Length. Not used by JADS.
Bit 4-15 Data. Valid only for long messages.

3.3.3 Deleted Data

A message in response to a command for the deleted data. The Deleted Data message provides the ADT operator with message type, serial number and deletion code for each downlink message that is deleted up to thirty-one messages. This message will not be implemented on the T-1 interface.

3.3.4 Status

The Status message provides the status information for the ADT. This message will not be implemented on the T-1 LAN interface.

APPENDIX G

Software Test Plan

for the

JADS

Ground Data Terminal 1553 Bus Interface Unit

11527-117-1 21 April 1997

Revision - 21 April 1997

SOFTWARE TEST PLAN

for the

JADS
Ground Data Terminal 1553 Bus Interface Unit

CONTRACT NO. DAAB07-96-C-S201

CDRL SEQUENCE NO. (NONE)

Prepared for:

Joint Advanced Distributed Simulation
Joint Test & Evaluation
1951 2nd Street SE
Kirtland AFB, NM 87117-5617

Prepared by:

MOTOROLA

Space and Systems Technology Group
8201 E. McDowell Road
P.O. Box 1417

Scottsdale, AZ 85252

1 SCOPE

1.1 Identification

This software test plan (STP) applies to the computer software configuration item (CSCI) portion of the Ground Data Terminal (GDT) 1553 Bus Interface Unit (1553 BIU). The development of the GDT 1553 BIU is under the direction of the Joint Advanced Development Simulation (JADS) Joint Test and Evaluation (JT&E) End-to-End Test (ETE) organization at Kirtland AFB in New Mexico.

1.2 System Overview

The JADS JT&E organization is charged with developing the capability to test and evaluate the Joint STARS system performance through a hardware-in-the-loop simulation. One element of this simulation is the interface between the Common Ground Station (CGS) and the E-8C aircraft. This interface is normally an RF link. The link is to be simulated by sending link data over a dedicated T1 line. This requires the development of interface software at both ends of the T1 line to make the data look like it had traversed the Surveillance Control Data Link (SCDL) rather than a WAN based digital connection. The specific software under test here is the interface software for the CGS end of the T1 line.

1.3 Document Overview

This STP describes the formal qualification test plans for the GDT 1553 BIU. It identifies the software test environment resources required for formal qualification testing (FQT) and provides schedules for FQT activities. In addition, it identifies the individual tests that shall be performed during FQT.

1.4. Relationship to Other Plans

There are no other plans related to this particular activity at the current contract level.

2. Referenced Documents

Document Number	Document Title	Document Date
JADS-ICD-002	Interface Control Document for the Ground Station Module T-1 LAN Interface of the Radar Processor and Integrator for Joint STARS	January 1997
C99ICDVA331	Interface Control Document (ICD) for Ground Station Module (GSM) Target Acquisition Subsystem to Ground Data Terminal (GDT) Group OZ-64/GRY Containing LRU's Nomenclatured (V)3/G	15 April 1996

3. Software Test Environment

3.1 Software Items

The software items necessary to perform the FQT activities include:
Sun Solaris operating system,
Sun C++ compiler,
EDT 1553 device driver,
GDT 1553 BIU application code,
CGS 1553 test drivers, and
ADT 802.3 test drivers.

3.2 Hardware and Firmware Items

The computer hardware, interfacing equipment, and firmware items that will be used in the software test environment include:

Sun SPARC 5 computer (the application host),
Sun computer (the 802.3 interface emulator),
Sun computer (the 1553 interface emulator),
Joint STARS Common Ground Station (CGS),
JADS supplied IDNX,
JADS supplied KIV-7HS, and
JADS supplied CSU/DSU.

The test environment for CSCI testing will be unclassified. The test environment for system level testing may include classified information. Whether or not the system level test information is classified, the testing will include encryption / decryption equipment as part of the test setup.

3.3 Propritary Nature and Government Rights

There are no proprietary rights on the developed software, hardware, or firmware.

3.4 Installation, Testing and Control

The GDT 1553 BIU application code will be installed on the Sun SPARC 5 computer prior to test. The application code and all test software will be maintained under Configuration Management Version Control (CMVC) prior to and during the tests.

4. Formal Qualification Test Identification

4.1 GDT 1553BIU CSCI

4.1.1 General Test Requirements

The formal qualification of the GDT 1553 BIU CSCI shall involve the use of nominal input values. Testing with erroneous input values will not be included.

4.1.2 Test Classes

The formal qualification testing of the GDT 1553 BIU CSCI shall include functional tests and timing tests.

4.1.3 Test Levels

The formal qualification testing of the GDT 1553 BIU CSCI shall be performed at two levels:

a. CSCI level--to evaluate compliance with CSCI requirements. These tests include test definitions 4.1.4.1 through 4.1.4.9.
b. System level--to validate that the SCDL interface performs properly in the absence of the real GDT. These tests will be similar in nature to the tests performed for CSCI testing, but they will generally be performed with real 1553 and 802.3 interfaces rather than the interface emulators used in the CSCI testing. These tests include test definitions 4.1.4.10 through 4.1.4.14

4.1.4 Test Definitions

4.1.4.1 GDT Initial Status

a. Test objective: Verify that the initial GDT status reports indicate that the uplink and downlink are not enabled and that the other status report elements are correct for this condition.

b. Special requirements: For this test, the 1553 emulator must not send a control message that enables the uplink or downlink.

c. Test level: CSCI.

d. Test type or class: Functional.

e. Qualification method: Demonstration.

f. Type of data to be recorded: GDT Status Reports.

g. Assumptions and constraints: None.

4.1.4.2 GDT Initial Status Message Blocking

a. Test objective: Verify that uplink and downlink traffic are not passed through the GDT 1553 BIU.

b. Special requirements: For this test, the 1553 emulator must not send a control message that enables the uplink or downlink.

c. Test level: CSCI.

d. Test type or class: Functional.

e. Qualification method: Demonstration.

f. Type of data to be recorded: Presence or absence of uplink messages at the 802.3 interface or downlink messages at the 1553 interface.

g. Assumptions and constraints: The 1553 interface emulator is sending uplink messages and the 802.3 emulator is sending downlink messages.

4.1.4.3 GDT Initial Status Transition

a. Test objective: Verify that the GDT status reports indicate that the uplink and downlink are enabled after receipt of the uplink and downlink enabling control messages from the 1553 emulator.

b. Special requirements: For this test, the 1553 emulator must first enable the downlink and then enable the uplink.

c. Test level: CSCI.

d. Test type or class: Functional.

e. Qualification method: Demonstration.

f. Type of data to be recorded: GDT Status Reports.

g. Assumptions and constraints: The GDT 1553 BIU must start this test in the Initial Status Mode of paragraph 4.1.4.1.

4.1.4.4 GDT Uplink Messages

a. Test objective: Verify that uplink traffic is correctly passed through the GDT 1553 BIU.

b. Special requirements: For this test, the 1553 emulator must have already enabled the uplink and downlink.

c. Test level: CSCI.

d. Test type or class: Functional.

e. Qualification method: Demonstration.

f. Type of data to be recorded: Uplink messages at the 802.3 interface.

g. Assumptions and constraints: The 1553 emulator is providing periodic uplink messages.

4.1.4.5 GDT Uplink Message Latency

a. Test objective: Verify that uplink traffic is correctly passed through the GDT 1553 BIU with a latency of less than 100 milliseconds.

b. Special requirements: For this test, the 1553 emulator must have already enabled the uplink and downlink.

c. Test level: CSCI.

d. Test type or class: Timing.

e. Qualification method: Demonstration.

f. Type of data to be recorded: Time of Uplink message appearance at the 1553 and 802.3 interfaces.

g. Assumptions and constraints: The 1553 emulator is providing periodic uplink messages.

4.1.4.6 GDT Downlink Messages

a. Test objective: Verify that downlink traffic is correctly passed through the GDT 1553 BIU.

b. Special requirements: For this test, the 1553 emulator must have already enabled the uplink and downlink.

c. Test level: CSCI.

d. Test type or class: Functional.

e. Qualification method: Demonstration.

f. Type of data to be recorded: Downlink messages at the 1553 interface.

g. Assumptions and constraints: The 802.3 emulator is providing periodic downlink messages.

4.1.4.7 GDT Downlink Message Latency

a. Test objective: Verify that downlink traffic is correctly passed through the GDT 1553 BIU with a latency of less than 100 milliseconds.

b. Special requirements: For this test, the 1553 emulator must have already enabled the uplink and downlink.

c. Test level: CSCI.

d. Test type or class: Timing.

e. Qualification method: Demonstration.

f. Type of data to be recorded: Downlink messages at the 1553 interface.

g. Assumptions and constraints: The 802.3 emulator is providing periodic downlink messages.

4.1.4.8 GDT Aircraft Location Messages

a. Test objective: Verify that the Aircraft Location Message is correctly converted and passed through the GDT 1553 BIU in the GDT Status Report.

b. Special requirements: For this test, the 1553 emulator must have already enabled the uplink and downlink.

c. Test level: CSCI.

d. Test type or class: Functional.

e. Qualification method: Demonstration.

f. Type of data to be recorded: GDT Status Reports at the 1553 interface.

g. Assumptions and constraints: The 802.3 emulator is providing periodic aircraft location messages.

4.1.4.9 GDT Traffic Capacity

a. Test objective: Verify that GDT 1553 BIU traffic capacity is sufficient to pass 28 Downlink messages and one Uplink message, to process one Aircraft Location message, to provide one GDT Status message and two Transmit Vector Words messages during a 100 millisecond time interval.

b. Special requirements: For this test, the 1553 emulator must have already enabled the uplink and downlink.

c. Test level: CSCI.

d. Test type or class: Timing.

e. Qualification method: Demonstration.

f. Type of data to be recorded: Time of Uplink message appearance at the 1553 and 802.3 interfaces; time of Downlink message appearance at the 802.3 and 1553 interfaces; time of Aircraft Location messages appearance at the 802.3 interface; and time of GDT Status and TVW messages appearance at the 1553 interfaces.

g. Assumptions and constraints: All required messages are provided to the GDT 1553 BIU CSCI at the proper rates.

4.1.4.10 GDT Initial Status

a. Test objective: Verify that the initial GDT status reports indicate that the uplink and downlink are not enabled and that the other status report elements are correct for this condition.

b. Special requirements: For this test, the CGS must not send a control message that enables the uplink or downlink.

c. Test level: System.

d. Test type or class: Functional.

e. Qualification method: Demonstration.
f. Type of data to be recorded: GDT Status Reports.
g. Assumptions and constraints: None.

4.1.4.11 GDT Initial Status Transition

a. Test objective: Verify that the GDT status reports indicate that the uplink and downlink are enabled after receipt of the uplink and downlink enabling control messages from the 1553 emulator.
b. Special requirements: For this test, the CGS must first enable the downlink and then enable the uplink.
c. Test level: System.
d. Test type or class: Functional.
e. Qualification method: Demonstration.
f. Type of data to be recorded: GDT Status Reports.
g. Assumptions and constraints: The GDT 1553 BIU must start this test in the Initial Status Mode of paragraph 4.1.4.7.

4.1.4.12 GDT Uplink Messages

a. Test objective: Verify that uplink traffic is correctly passed through the GDT 1553 BIU.
b. Special requirements: For this test, the CGS must have already enabled the uplink and downlink.
c. Test level: System.
d. Test type or class: Functional.
e. Qualification method: Demonstration.
f. Type of data to be recorded: Uplink messages at the E-8C interface at Northrop / Grumman.
g. Assumptions and constraints: The CGS is providing periodic uplink messages.

4.1.4.13 GDT Downlink Messages

a. Test objective: Verify that downlink traffic is correctly passed through the GDT 1553 BIU.
b. Special requirements: For this test, the CGS must have already enabled the uplink and downlink.
c. Test level: System.
d. Test type or class: Functional.
e. Qualification method: Demonstration.
f. Type of data to be recorded: Downlink messages at the CGS.
g. Assumptions and constraints: The E-8C is providing periodic downlink messages.

4.1.4.14 GDT Aircraft Location Messages

a. Test objective: Verify that the Aircraft Location Message is correctly converted and passed through the GDT 1553 BIU in the GDT Status Report.

b. Special requirements: For this test, the CGS must have already enabled the uplink and downlink.

c. Test level: System.

d. Test type or class: Functional.

e. Qualification method: Demonstration.

f. Type of data to be recorded: GDT Status Reports.

g. Assumptions and constraints: The E-8C is providing periodic aircraft location messages.

4.1.5 Test schedule

The testing of the GDT 1553 BIU CSCI shall be accomplished as soon as practical after this STP receives JADS ETE approval and dry-run testing verifies that the software passes the tests in paragraphs 4.1.4.1 through 4.1.4.9 of this STP. The system level testing of the GDT 1553 BIU CSCI shall be accomplished as soon as practical after completion of the CSCI level testing. The system level tests are defined in paragraphs 4.1.4.10 through 4.1.4.14.

5. Data Recording, Reduction, and Analysis

The data reduction and analysis required during and following the tests identified in this STP will be comparison of GDT Status Reports, Uplink Messages, and Downlink Messages with their respective expected values and evaluation of appropriate timing entries for message transmit and receipt. No data retention will be required other than logbook entries and printouts generated during the tests.

6. NOTES

None.

JADS BIU Qualification Test Procedure

Three test configurations are identified herein to support the test levels and definitions described by the previously submitted Software Test Plan. This procedure describes each test configuration, tests conducted for that configuration, and a brief procedure for each test. All test definitions from the Software Test Plan are included within this procedure; however , they will be executed in accordance with the test configuration order presented below.

Test Configuration I

Software Emulation of CGS running on JADS BIU workstation

JADS BIU Software running on JADS BIU workstation

Software emulation of T1 Link running on "Kong" workstation

Triax termination on Primary 1553 connector which links the CGS emulation software to the JADS BIU software via 1553 bus.

Ethernet Link between JADS BIU and "Kong" network

When each of the three software components have been initiated, the CGS Emulator will send control messages and uplink messages (rate = 0.1 Hz) to the BIU over the 1553 bus, automatically triggering the GDT status transitions. The T1 link emulator software, upon receiving the first uplink message from the BIU over the Ethernet link, will respond by sending downlink messages (rate = 80 Hz) and aircraft location messages (rate = 1 Hz). When the JADS BIU software transitions to the downlink enabled mode, it will pass the messages through the 1553 bus where they will be detected by the CGS Emulator software. Results of the tests will be verified by examination of log files generated as the above scenario is executed.

Test Configuration I Coverage

a) GDT Initial Status (STP Paragraph 4.1.4.1)

Verify Control Word portion of initial GDT Status Report from CGS Emulator Log File

b) GDT Initial Status Message Blocking (STP Paragraph 4.1.4.2)

Examine JADS BIU Log File to verify that Uplink messages are counted only when Uplink is enabled, and that Downlink messages are counted only when downlink is enabled.

c) GDT Initial Status Transition (STP Paragraph 4.1.4.3)

Examine JADS BIU Log File to verify that Uplink Enabled and Downlink enabled mode transitions take place.

d) GDT Uplink Messages (STP Paragraph 4.1.4.4)

Examine T1 Emulator Log File to verify the indication of test uplink messages passed through the JADS BIU and transmitted via Ethernet to the "Kong" workstation.

e) GDT Uplink Message Latency (STP Paragraph 4.1.4.5)

Examine JADS BIU Log File to record maximum and average Uplink latency values in milliseconds.

f) GDT Downlink Messages (STP Paragraph 4.1.4.6)

Examine JADS BIU Log File to record maximum and average Uplink latency values in milliseconds.

g) GDT Aircraft Location Messages (STP Paragraph 4.1.4.7)

Examine CGS Emulator Log Files to verify the indication of Aircraft Location data updating the appropriate fields of the GDT Status message.

Test Configuration II

CGS Server 1553 connection to provide downlink data request

JADS BIU Software running on JADS BIU workstation

Software emulation of T1 Link running on "Kong" workstation

Cable connection between Primary 1553 connector which links the CGS server to the JADS BIU software via 1553 bus.

Ethernet Link between JADS BIU and "Kong" network

Requests for downlink data are generated periodically (20 Hz) by the CGS Server. The T1 link software emulation generates aircraft location & downlink messages at a rate which is comparable to that supported by the actual T1 link maximum. Uplink messages will be generated from the CGS workstation console, and when the first message is passed through the JADS BIU to the T1 emulation software, downlink and aircraft location message transmission will begin. Results of the tests will be verified by log files generated on the JADS BIU workstation.

Test Configuration II Coverage

a) GDT Downlink Latency (STP Paragraph 4.1.4.7)

Examine JADS BIU Log File to record maximum and average Downlink latency values in milliseconds.

b) GDT Traffic Capacity (STP Paragraph 4.1.4.9)

Examine JADS BIU Log File to record maximum throughput rate in messages per second.

Test Configuration III

CGS Server 1553 connection to JADS BIU workstation

E8 Aircraft Simulator Connection to JADS BIU workstation (T1/ IDNX)

The workstation will require re-configuration and re-boot to incorporate new IP address and port data , which are necessary to support its operational configuration.

Test Configuration III Coverage

a) GDT Initial Status (STP Paragraph 4.1.4.10)

Capture GDT Status report at CGS Console using Bus Monitor Log facility.

b) GDT Initial Status Transition (STP Paragraph 4.1.4.11)

Use CGS Manage Links controls and periodic status displays on JADS BIU console to verify the status transitions.

c) GDT Aircraft Location Messages (STP Paragraph 4.1.4.14)

Use CGS Workstation Imagery window to display the simulated E - 8C flight path.

d) GDT Uplink Messages (STP Paragraph 4.1.4.12)

Generate RSR & Freetext messages using CGS Workstation and confirm receipt at Grumman facility.

e) GDT Downlink Messages (STP Paragraph 4.1.4.12)

Use CGS Message Alert facility to display Freetext message originated from the simulated E - 8C ; use imagery window to display MTI & SAR imagery patterns.

APPENDIX H

Memorandum for Record

Characterization Reports

From

JADS JTF/ETE (N&E)

MEMORANDUM FOR RECORD 16 Dec 97

FROM : JADS JTF/ETE(N&E)

SUBJECT: Characterization Report

1. Event Name: TCAC-Grumman T-1 Characterization.

2. Date/Time: 1 Dec 97; 1100 - 1500.

3. Site(s): Grumman - Melbourne, FL; JADS TCAC - Albuquerque, NM.

4. Description: The characterization involved base-lining the performance of the T-1 link between Grumman and the TCAC. A variety of Networking and Engineering tests were used to calculate the round trip latencies and determine the maximum rate at which DIS PDUs could be transmitted before drop-outs occurred. The tests used to gather this data included the No Load Latency Test, the Loaded Latency Test, PDU Verification Test and the Stress Test. Additionally, Spectrum recorded the bandwidth utilized across the T-1 link.

5. Objective: Assess (characterize) the TCAC-Grumman T-1 Link with and without network analysis tools operating.

5.1 Determine the "no load" latency using pings.
5.2 Determine the loaded latency using pings at varying rates.
5.3 Successful transmission of DIS PDUs across the link.
5.4 Determine the packet rate (packets per second) in which DIS PDUs are lost.
5.5 Determine the impact of Spectrum on latencies and data rates.

6. Results:

6.1. Data Recorded (**with** Spectrum operational)

6.1.1 No Load Latency Test: The first test conducted was the no load latency test using *pings*. This test involved using 32 *pings* for measuring the baseline round trip latency from the TCAC to Grumman. The minimum load for these pings were 64 bytes. This test yielded the following results:

Table 6.1.1. Latency Test - No Load

Date	Source	Destination	No. Pkts	Round-trip Time (ms) Minimum	Maximum	Average
1 Dec 97	TCAC_Indy	Grumman_Indy	32	57	71	57

6.1.2. Loaded Latency Test: The second test consisted of transmitting loaded pings, 144 bytes, at several different rates and packet sizes to determine the round trip latencies– see table 6.1.2.

Table 6.1.2. Latency Test - Loaded

Date	Source	Destination	Pkt Rate(sec)	Pkts Sent/Rec	Round-trip Time (ms) Min	Max	Ave
1 Dec 97	TCAC_Indy	Grumman_Indy	.01	320/320	58	163	60
			.005	640/639	58	61	58
			.0025	1280/1279	58	124	58
			.00125	2560/2559	58	167	58

6.1.3. PDU Verification Test: The next test used PDUs generated at 100 packets per second from JANUS and recorded by the JADS logger. The PDUs were replayed from the TCAC and logged at Grumman – see table 6.1.3.

Table 6.1.3. PDU Verification Test

Date	Location	No. of PDUs Received	No. of PDUs Transmitted	No. of PDUs Out-of-order	No. of PDUs > 1 sec.
5 Nov 97	Grumman	11859	11859	0	0

6.1.4. Stress Test: This test involved replaying the ESPDU file at its recorded excepted data rate (EDR), then increasing the EDR by 100 packets per second incrementally to five times the EDR. During the actual playback of the PDU log file, *pings* were transmitted and latency statistics recorded. Spectrum also recorded the bandwidth utilized.

Table 6.1.4. Stress Test

	Rate (PDU/sec)	Ping Time (ms) Min/Max/Ave	Number PDUs Received	Bandwidth Util. (%)
1 X E.R.	100	60/120/61	11859	10
2 X E.R.	200	59/90/68	11858	21
3 X E.R.	300	59/90/64	11853	28
4 X E.R.	400	57/210/79	11847	40
5 X E.R.	500	57/840/256	10492	45

6.2. Data Recorded (**without** Spectrum operational)

6.2.1 No Load Latency Test: The first test conducted was the no load latency test using *pings*. This test involved using 32 *pings* for measuring the baseline round trip latency from the TCAC to Grumman. The minimum load for these *pings* were 64 bytes. This test yielded the following results:

Table 6.2.1. Latency Test - No Load

				Round-trip Time (ms)		
Date	Source	Destination	No. Pkts	Minimum	Maximum	Average
1 Dec 97	TCAC_Indy	Grumman_Indy	32	57	76	57

6.2.2. Loaded Latency Test: The second test consisted of transmitting loaded *pings*, 144 bytes, at several different rates and packet sizes to determine the round trip latencies– see table 6.2.2.

Table 6.2.2. Latency Test - Loaded

			Pkt	Pkts	Round-trip Time (ms)		
Date	Source	Destination	Rate(sec)	Sent/Rec	Min	Max	Ave
1 Dec 97	TCAC_Indy	Grumman_Indy	.01	320/320	58	60	58
			.005	640/639	58	64	58
			.0025	1280/1279	58	101	58
			.00125	2560/2559	58	161	58

6.2.3. PDU Verification Test: The next test used PDUs generated at 100 packets per second from JANUS and recorded by the JADS logger. The PDUs were replayed from the TCAC and logged at Grumman – see table 6.2.3.

Table 6.2.3. PDU Verification Test

Date	Location	No. of PDUs Received	No. of PDUs Transmitted	No. of PDUs Out-of-order	No. of PDUs > 1 sec.
5 Nov 97	Grumman	11859	11859	0	0

6.2.4. Stress Test: The last test conducted was the Stress Test. The test involved replaying the ESPDU file at its recorded EDR, then increasing the EDR by 100 packets per second incrementally to five times the EDR. During the actual playback of the PDU log file, *pings* were transmitted and latency statistics recorded; however, bandwidth data was not collected.

Table 6.2.4. Stress Test

	Rate (PDU/sec)	Ping Time (ms) Min/Max/Ave	Number PDUs Received	Bandwidth Util. (%)
1 X E.R.	100	60/70/60	11859	
2 X E.R.	200	58/92/62	11858	
3 X E.R.	300	59/89/63	11853	
4 X E.R.	400	57/120/71	11848	
5 X E.R.	500	57/600/216	10759	

6.3. Problems:

6.3.1. The characterization process was delayed for a couple of hours due to the monthly crypto reloading.

6.3.2. During the PDU Verification test additional DIS PDUs were being logged at the Grumman_Indy computer. The DIS PDUs logged at Grumman exceeded the number contained in the replayed log file sent from the TCAC. The Grumman_Indy computer can receive data from both Grumman and the TCAC. The test coordinator contacted Grumman and inquired as to whether they had a system broadcasting to the Grumman_Indy computer on port 3000. Grumman's initial response to our question was no. Upon our investigation, which consisted of viewing traffic along port 3000, we observed the Grumman_Indy computer receiving data long after we had stopped broadcasting. Apparently, Grumman had concluded a test last week, but their Alpha computer was still sending data to port 3000. Finally, Grumman disconnected their Alpha computer and we resumed testing with no further problems or delays.

6.3.3. The IDNX router card throughput is presently less than the vendor's specification and the allocated capacity of the T-1 link. The performance can be improved if we used bridging as opposed to Internet Protocol (IP) routing of DIS PDUs. This procedure was assessed using the JADS testbed. The effect of bridging doubled the reliable transmitted data rate to 800 packets per second. However, this configuration does not support the current network design of the ETE test. The vendor was contacted about the shortcoming, and they are pursuing every avenue to determine if the performance problem is their software, Cisco's software, or hardware related.

6.3.4 Although the utilized bandwidth was accurately recorded using Spectrum for one, two, and three times the EDR, the values for four and five times seemed lower than expected. The percentages were 20 and 19, respectively. The data collection sampling interval was initial set for every 30 seconds. Consequently, the DIS PDUs were not replayed within the time window and the results were not representative of the EDR. The settings were reduced to 10 second intervals and Spectrum's packet rate data was monitored to ensure the values reflected the EDR.

6.3.5. The maximum value recorded for each set of pings represented an outlier of the data set. This maximum value far exceeded the values recorded and consistently appeared at the beginning of the recorded data set. Since this anomaly happened infrequently during a ping data set, the results were not statistically significant. N&E will continue to investigate this issue.

6.4. Summary: At 1000hrs the characterization team began the preliminary checks of the network. About one hour later, the characterization began and each one of the tests was executed in sequence. The test results were stable and fairly predicable. During the Stress Test several DIS PDUs were lost at three and four times the EDR but did not achieve a notable percentage. However, at five times the EDR several hundred DIS PDUs were dropped--approximately nine percent. Currently, the highest EDR transmissions across this link should not exceed 400 packets per second; therefore, the link can successfully handle the expected traffic. The characterization test also involved capturing the impact of the network analysis tool. The results indicated that Spectrum minimally increased the amount of network traffic and added an insignificant amount of latency.

GREGORY P. DEWIT
CPT(P), FA
Test Analyst

MEMORANDUM FOR RECORD 26 Feb 98

FROM : JADS JTF/ETE/N&E

SUBJECT: ETE Characterization Report

1. Event Name: White Sands Missile Range (WSMR)/TCAC-A Annex T-1 Characterization.

2. Date/Time: 3 Feb 98; 1100 - 1500.

3. Sites: WSMR, NM; JADS TCAC - Albuquerque, NM.

4. Description: The characterization involved base-lining the performance of the T-1 link between WSMR and the TCAC-A. A variety of Networking and Engineering tests were used to calculate the round trip latencies and determine the maximum rate at which DIS PDUs could be transmitted before drop-outs occurred. The tests used to gather this data included the No Load Latency Test, the Loaded Latency Test, PDU Verification Test, and the Stress Test.

5. Objective: Assess (characterize) the WSMR/TCAC-A T-1 link.
   - 5.1 Determine the "no load" latency using pings.
   - 5.2 Determine the loaded latency using pings at varying rates.
   - 5.3 Successful transmission of DIS PDUs across the link.
   - 5.4 Determine the packet rate (packets per second) in which DIS PDUs are lost.

6. Results:

6.1. Data Recorded.

6.1.1 No Load Latency Test: The first test conducted was the no load latency test using *pings*. This test involved using 32 *pings* for measuring the baseline round trip latency from the TCAC to WSMR. The minimum load for these pings were 64 bytes. This test yielded the following results:

Table 6.1.1. Latency Test - No Load

				Round-trip Time (ms)		
Date	Source	Destination	No. Pkts	Minimum	Maximum	Average
1 Dec 97	TCAC_Indy	WSMR Indy	32	41	44	41

6.1.2. Loaded Latency Test: The second test consisted of transmitting loaded pings, 144 bytes, at different rates and packet sizes to determine round trip latencies– see table 6.1.2.

Table 6.1.2. Latency Test - Loaded

Date	Source	Destination	Pkt Rate(sec)	Pkts Sent/Rec	Round-trip Time (ms) Min	Max	Ave
1 Dec 97	TCAC_Indy	WSMR Indy	.01	320/320	42	45	42
			.005	640/639	42	85	42
			.0025	960/960	42	51	42

6.1.3. PDU Verification Test: The next test used PDUs generated at 100 packets per second from JANUS and recorded by the JADS logger. The PDUs were replayed from the TCAC and logged at WSMR – see table 6.1.3.

Table 6.1.3. PDU Verification Test

Date	Location	No. of PDUs Received	No. of PDUs Transmitted	No. of PDUs Out-of-order	No. of PDUs > 1 sec.
5 Nov 97	WSMR	11859	11859	0	0

6.1.4. Stress Test: This test involved replaying the ESPDU file at its recorded excepted data rate (EDR), then increasing the EDR by 100 packets per second incrementally to five times the EDR. During the actual playback of the PDU log file, *pings* were transmitted and latency statistics recorded. Spectrum also recorded the bandwidth utilized.

Table 6.1.4. Stress Test

	Rate (PDU/sec)	Ping Time (ms) Min/Max/Ave	Number PDUs Received
1 X E.R.	100	59/61/59	11859
2 X E.R.	200	41/61/59	11858
3 X E.R.	300	41/60/45	11853
4 X E.R.	400	41/61/58	11850
5 X E.R.	500	41/70/56	11849

6.2. Problems: PDUs were lost during the execution of the Stress Test. N&E continues to investigate packet drop-outs.

6.3. Summary: During the execution of the characterization, latencies and PDU drop-outs were less than anticipated. Unlike several other T-1 links characterized while using a routed network configuration, WSMR used bridging. This technique provided a much more stable environment thus allowing for lower transmission latencies and fewer PDU losses. Each characterization test was conducted and the results annotated in the previous tables. The WSMR/TCAC-A link can support the maximum expected data rate of 400 PDUs per second.

GREGORY P. DEWIT
CPT(P), FA
Test Analyst

MEMORANDUM FOR RECORD 26 Feb 98

FROM : JADS JTF/ETE/N&E

SUBJECT: Characterization Report

1. Event Name: Fort Hood/TCAC-A Annex T-1 Characterization.

2. Date/Time: 2 Feb 98; 0900 - 1100.

3. Sites: Fort Hood, TX; JADS TCAC - Albuquerque, NM.

4. Description: The characterization involved base-lining the performance of the T-1 link between Fort Hood and the TCAC-A. A variety of Networking and Engineering tests were used to calculate the round trip latencies and determine the maximum rate at which DIS PDUs could be transmitted before drop-outs occurred. The tests used to gather this data included the No Load Latency Test, the Loaded Latency Test, PDU Verification Test, and the Stress Test.

5. Objective: Assess (characterize) the Fort Hood/TCAC-A T-1 link.
   - 5.1 Determine the "no load" latency using pings.
   - 5.2 Determine the loaded latency using pings at varying rates.
   - 5.3 Successful transmission of DIS PDUs across the link.
   - 5.4 Determine the packet rate (packets per second) in which DIS PDUs are lost.

6. Results:

6.1. Data Recorded.

6.1.1 No Load Latency Test: The first test conducted was the no load latency test using *pings*. This test involved using 32 *pings* for measuring the baseline round trip latency from the TCAC to Fort Hood. The minimum load for these pings were 64 bytes. This test yielded the following results:

Table 6.1.1. Latency Test - No Load

Date	Source	Destination	No. Pkts	Round-trip Time (ms)		
				Minimum	Maximum	Average
1 Dec 97	TCAC_Indy	Fort Hood Indy	32	37	77	38

6.1.2. Loaded Latency Test: The second test consisted of transmitting loaded pings, 144 bytes, at several different rates and packet sizes to determine the round trip latencies– see table 6.1.2.

Table 6.1.2. Latency Test - Loaded

Date	Source	Destination	Pkt Rate(sec)	Pkts Sent/Rec	Round-trip Time (ms) Min	Max	Ave
1 Dec 97	TCAC_Indy	Fort Hood Indy	.01	320/320	38	39	38
			.005	640/639	39	55	39
			.0025	960/960	38	76	39

6.1.3. PDU Verification Test: The next test used PDUs generated at 100 packets per second from JANUS and recorded by the JADS logger. The PDUs were replayed from the TCAC and logged at Fort Hood – see table 6.1.3.

Table 6.1.3. PDU Verification Test

Date	Location	No. of PDUs Received	No. of PDUs Transmitted	No. of PDUs Out-of-order	No. of PDUs > 1 sec.
5 Nov 97	Fort Hood	11859	11859	0	0

6.1.4. Stress Test: This test involved replaying the ESPDU file at its recorded excepted data rate (EDR), then increasing the EDR by 100 packets per second incrementally to five times the EDR. During the actual playback of the PDU log file, *pings* were transmitted and latency statistics recorded. Spectrum also recorded the bandwidth utilized.

Table 6.1.4. Stress Test

	Rate (PDU/sec)	Ping Time (ms) Min/Max/Ave	Number PDUs Received
1 X E.R.	100	40/69/59	11859
2 X E.R.	200	37/60/42	11858
3 X E.R.	300	50/60/59	11853
4 X E.R.	400	38/61/58	11859
5 X E.R.	500	37/61/54	11859

6.2. Problems: PDU drop-out is a reoccurring problem during the Stress Test. N&E is still investigating.

6.3. Summary: The Fort Hood/TCAC-A bridged link was characterized in less than four hours. The appropriate data was gathered and appears in the tables mentioned earlier. There latencies were stable throughout the execution of each test. The link can support more than the maximum expected data rate with only a couple of PDUs dropped. A bridged network seems to offer faster transmission rates and fewer PDU drop-outs.

GREGORY P. DEWIT
CPT(P), FA
Test Analyst

MEMORANDUM FOR RECORD 26 Feb 98

FROM : JADS JTF/ETE/N&E

SUBJECT: Characterization Report

1. Event Name: Fort Sill/TCAC-A Annex T-1 Characterization.

2. Date/Time: 2 Feb 98; 1300 - 1600.

3. Sites: Fort Sill, OK; JADS TCAC - Albuquerque, NM.

4. Description: The characterization involved base-lining the performance of the T-1 link between Fort Sill and the TCAC-A. A variety of Networking and Engineering tests were used to calculate the round trip latencies and determine the maximum rate at which DIS PDUs could be transmitted before drop-outs occurred. The tests used to gather this data included the No Load Latency Test, the Loaded Latency Test, PDU Verification Test, and the Stress Test.

5. Objective: Assess (characterize) the Fort Sill/TCAC-A T-1 link.
   - 5.1 Determine the "no load" latency using pings.
   - 5.2 Determine the loaded latency using pings at varying rates.
   - 5.3 Successful transmission of DIS PDUs across the link.
   - 5.4 Determine the packet rate (packets per second) in which DIS PDUs are lost.

6. Results:

6.1. Data Recorded.

6.1.1 No Load Latency Test: The first test conducted was the no load latency test using *pings*. This test involved using 32 *pings* for measuring the baseline round trip latency from the TCAC to Fort Sill. The minimum load for these pings were 64 bytes. This test yielded the following results:

Table 6.1.1. Latency Test - No Load

				Round-trip Time (ms)		
Date	Source	Destination	No. Pkts	Minimum	Maximum	Average
1 Dec 97	TCAC_Indy	Indy	32	30	40	30

6.1.2. Loaded Latency Test: The second test consisted of transmitting loaded pings, 144 bytes, at several different rates and packet sizes to determine the round trip latencies– see table 6.1.2.

Table 6.1.2. Latency Test - Loaded

Date	Source	Destination	Pkt Rate(sec)	Pkts Sent/Rec	Round-trip Time (ms) Min	Max	Ave
1 Dec 97	TCAC_Indy	Indy	.01	320/320	31	33	31
			.005	640/639	31	33	31
			.0025	960/960	31	33	31

6.1.3. PDU Verification Test: The next test used PDUs generated at 100 packets per second from JANUS and recorded by the JADS logger. The PDUs were replayed from the TCAC and logged at Fort Sill – see table 6.1.3.

Table 6.1.3. PDU Verification Test

Date	Location	No. of PDUs Received	No. of PDUs Transmitted	No. of PDUs Out-of-order	No. of PDUs > 1 sec.
5 Nov 97	Fort Sill	11859	11859	0	0

6.1.4. Stress Test: This test involved replaying the ESPDU file at its recorded excepted data rate (EDR), then increasing the EDR by 100 packets per second incrementally to five times the EDR. During the actual playback of the PDU log file, *pings* were transmitted and latency statistics recorded. Spectrum also recorded the bandwidth utilized.

Table 6.1.4. Stress Test

	Rate (PDU/sec)	Ping Time (ms) Min/Max/Ave	Number PDUs Received
1 X E.R.	100	30/61/58	11859
2 X E.R.	200	30/60/52	11857
3 X E.R.	300	30/61/43	11853
4 X E.R.	400	30/60/36	11859
5 X E.R.	500	30/84/300	10656

6.2. Problems: PDUs were lost during the execution of the Stress Test. N&E will continue to investigate packet drop-outs.

6.3. Summary: The Fort Sill/TCAC-A link involved using a router to transmit PDU packets. The latencies were reasonably close to the values during the Grumman Characterization given the shorter distance between Albuquerque and Fort Sill. There were a couple of packets lost while incrementing up to four times the EDR. The number of lost PDUs increased to about 10 percent of the packets transmitted at five times the EDR (500 packets per second).

GREGORY P. DEWIT
CPT(P), FA
Test Analyst

APPENDIX I

Joint Advanced Distributed Simulation Joint Test Force (JADS JTF)

LWX and Cisco Router Performance Test Report

Joint Advanced Distributed Simulation Joint Test Force (JADS JTF)

LWX and Cisco Router Performance Test Report

SUBJECT: **Integrated Digital Network Exchange (IDNX) LAN/WAN Exchange (LWX) and Cisco Router Performance Measurement in the Broadcasting/Forwarding of User Datagram Protocol Environment**

AUTHOR: **MSgt Charles P. Ashton, WAN Systems Engineer, Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF)**

Mason S. Ferratt, Systems Engineer Network Equipment Technologies (NET)

DATE: **December 18, 1997**

SUMMARY: This is a report of the performance, validation, and verification testing conducted on the LWX and external Cisco router platforms at the JADS-JTF facility, Albuquerque, NM. This document covers the steps taken during testing, the test results, conclusions drawn, and a discussion of the alternative solutions for the broadcasting of User Datagram Protocol (UDP) traffic through the JADS JTF End-to-End (ETE) network.

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1. Background

The Joint Advanced Distributed Simulation Joint Test Force (JADS JTF) has built a network of seven nodes to support an environment linking multiple simulation sites whose primary application is the broadcasting of User Datagram Protocol packets from multiple sites to multiple sites. The network supports the evaluation of Advanced Distributed Simulation (ADS) for the Department of Defense (DOD) Test and Evaluation (T&E) Community. The system is called the End-to-End Test Network and the system under test is the Joint Surveillance and Targeting Attack Radar System (JSTARS) and its associated command and control functions. The services carried by this network include the router traffic and voice traffic.

The goal of the testing conducted December 15-16, 1997 was to provide answers to whether the PX platforms (PX-3, PX-2, and APX) provided by NET could support the demands of the UDP traffic load through the JADS network.

2. Scope of Testing

1. Verification/validation of the problems witnessed by TSGT Ashton
2. Comparison of the performance gains/losses of external router configurations
3. Effects of altering internal software configuration (buffers, hold queues, etc.)
4. Effects of using a hybrid routed/bridged network
5. Effects of a completely bridged network

3. Description of PX-3 and LWX Rel. 3.01

The LAN/WAN Exchange (LWX) Release 3.01 is a general purpose router/bridge integrated into the Integrated Digital Network Exchange (IDNX) platform. It provides internetwork connectivity between Local Area Networks (LANs) over Wide Area Networks (WANs) through IDNX/ 90, /70, /20, and /Micro 20 IDNX nodes. The LWX 3.01, consists of a PX3 front card (revision B or later) and an Ethernet or Token Ring interface rear card, and provides:

— concurrent multi-protocol routing and fallback Media Access Control (MAC) layer bridging
— up to 8 logical serial connections to other LWXs or external routers
— an Ethernet interface rear card

The first phase of LWX 3.01 only supports four and eight port PX3 cards. Earlier LWX versions consisted of a PX- 2, PX- Plus, or Access PX front card and an Ethernet or Token Ring interface rear card, and provide only eight logical serial connections to other LWXs or external routers. LWX Release 3.01 supports only Ethernet and Token Ring (available in a later release) interface cards. LWX Release 3.01 must use a revision B (or later) PX3 card.

The JADS network uses four port PX3, eight port PX-2, and four port APX cards. The PX-3s run LWX Release 3.01 and the PX-2s and APXs run LWX Release 2.02.06. The LWX Release 3.01 is equivalent to Cisco's IOS Release 11.0(9). The LWX Release 2.02.06 is equivalent to Cisco's IOS Release 9.1(9).

4. Test Configurations

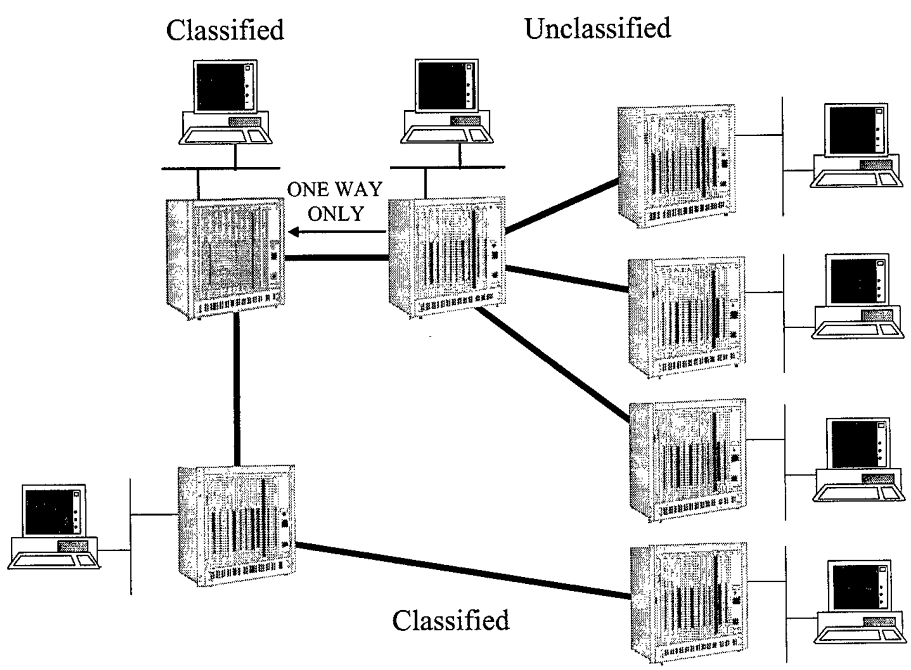

Figure 4-1 - JADS ETE Network Configuration

Figure 4-1 above illustrates a general configuration of the JADS ETE network. The connectivity between the nodes remained consistent throughout the testing. However, card and port configurations were varied for the different tests.

4.1 Point to Point PX-3

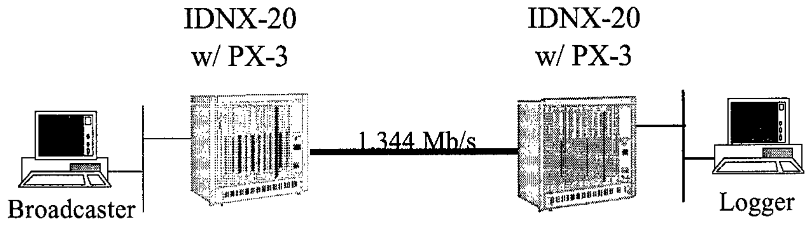

Figure 4.1-1 - PX-3 to PX-3 Configuration

Figure 4.1-1 above illustrates the setup used for the verification/validation using two PX-3s point-to-point.

4.2 Point to Point PX-3s to APX

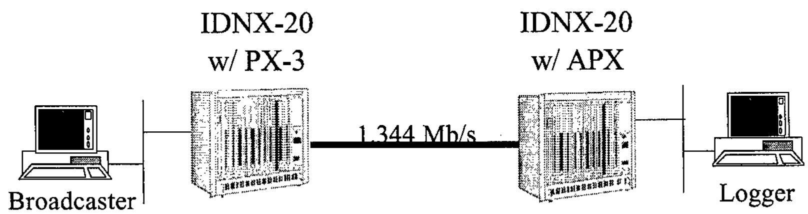

Figure 4.2-1 - PX-3 to APX Configuration

Figure 4.2-1 above illustrates the setup used for the verification/validation using one PX-3 and one APX point-to-point.

4.3 Cisco 4000 to PX-3

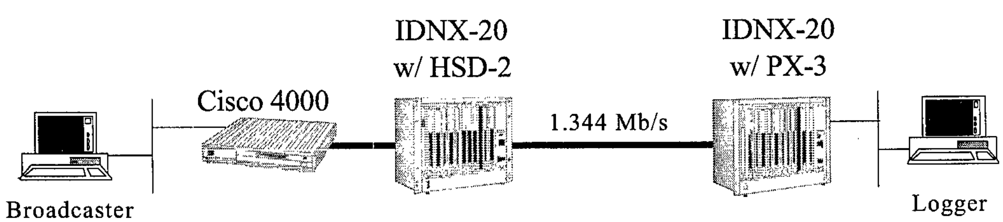

Figure 4.3-1 - Cisco 4000 to PX-3 Configuration

Figure 4.3-1 above illustrates the setup used for the verification/validation using an externally connected Cisco 4000 running Cisco IOS Release 9.1 to a PX-3 point-to-point. The Cisco 4000 was serially

connected through an HSD-2 port on the IDNX. The HSD-2 port was mapped to the distant end PX-3.

4.4 Cisco 7000 to PX-3

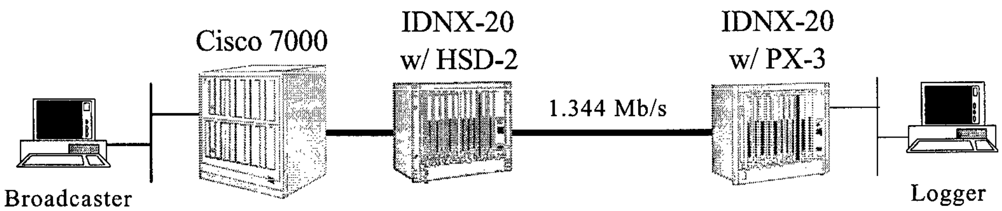

Figure 4.4-1 - Cisco 7000 to PX-3 Configuration

Figure 4.4-1 above illustrates the setup used for the verification/validation using an externally connected Cisco 7000 running Cisco IOS Release 11.x to a PX-3 point-to-point. The Cisco 7000 was serially connected through an HSD-2 port on the IDNX. The HSD-2 port was mapped to the distant end PX-3.

4.5 Cisco 7000 to 4000

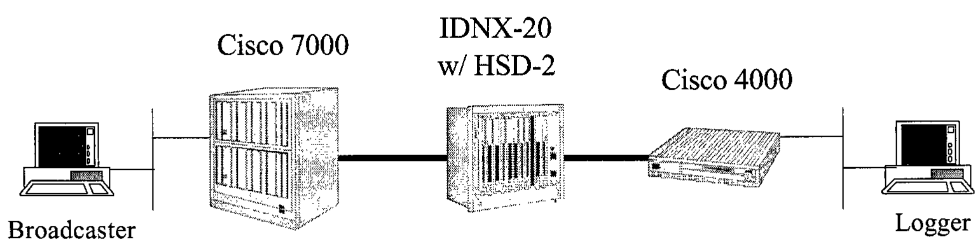

Figure 4.5-1 - Cisco 7000 to Cisco 4000 Configuration

Figure 4.5-1 above illustrates the setup used for the verification/validation using an externally connected Cisco 7000 running Cisco IOS Release 11.x to another externally connected Cisco 4000 point-to-point. Both Cisco routers were serially connected through HSD-2 ports on the IDNX. The HSD-2 ports were mapped end to end.

4.6 Multipoint UDP Forwarding & Hybrid Bridge/Router

IDNX-20
w/ PX-3

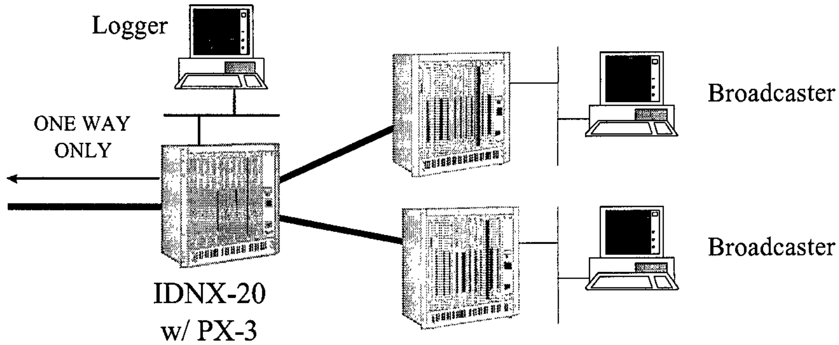

Figure 4.6-1 - Multipoint UDP Forwarding & Hybrid Bridge/Router Configuration

Figure 4.6-1 above illustrates the setup used for the verification/validation using multiple sources to broadcast DIS Entity State PDUs to a central logger. This configuration represents a portion of the unclassified side of the JADS ETE network.

5. Test Expectations

Throughout all the tests the Broadcaster, an SGI Indy workstation, used a file that consisted of 11,859 Distributed Interactive Simulation (DIS) Entity State protocol data units (PDUs). The SGI workstation broadcasted the PDUs on its local area network (LAN) as User Datagram Protocol (UDP) packets. The LWXs were configured to forward these broadcasts through the network. Each Entity State PDU was 144 bytes in length. The Internet Protocol (IP) datagram produced was 152 bytes in length. All this was verified using a Network General Sniffer Protocol Analyzer on the Broadcaster subnetwork.

At the distant end, the Logger, also an SGI Indy workstation, listened for UDP broadcasts and counted the number received. The difference is the number of packets dropped within the network.

We expected to see a threshold that each platform would reach in terms of performance. We knew that the unreliable nature of the traffic (UDP broadcasts) would force the routers to inspect each packet since it was a broadcast, and forward it onto each interface. This activity is known as process switching. The fact that every packet sent is process switched, we knew there had to be a limit to the number of packets successfully received when a workstation floods the network. We also expected to see very little improvement when changing the buffers and hold-queues. The fact remained that if packets are process-switched, there is a finite limit to speed in which it forwards packets successfully. We will discuss more about these issues in our conclusions.

The following two sections cover the result sets for the two separate environments (point-to-point and multipoint). The point-to-point environment results were used to gauge the expected results when we combined multiple stations broadcasting in the network. The multipoint configuration better represents the true network that will be fielded to support the JADS ETE network.

6. Performance Test Results (Point to Point - UDP forwarding)

Broadcaster generating 400 packets per second -

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 to PX-3	0	0
PX-3 to APX	0	0
Cisco 4000 to PX-3	0	0
Cisco 7000 to PX-3	0	0
Cisco 4000 to Cisco 7000	0	0
Cisco 7000 to Cisco 4000	0	0

Broadcaster generating 500 packets per second

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 to PX-3	2366	0
PX-3 to APX	2366	0
Cisco 4000 to PX-3	0	2366
Cisco 7000 to PX-3	0	2366
Cisco 4000 to Cisco 7000	0	0
Cisco 7000 to Cisco 4000	0	0

Broadcaster generating 600 packets per second

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 to PX-3	3927	0
PX-3 to APX	3927	0
Cisco 4000 to PX-3	0	3927
Cisco 7000 to PX-3	0	3927
Cisco 4000 to Cisco 7000	0	0
Cisco 7000 to Cisco 4000	0	0

Broadcaster generating 700 packets per second

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 to PX-3	4722	0
PX-3 to APX	4722	0
Cisco 4000 to PX-3	0	4722
Cisco 7000 to PX-3	0	4722
Cisco 4000 to Cisco 7000	0	0
Cisco 7000 to Cisco 4000	0	0

Broadcaster generating 800 packets per second

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 to PX-3	5646	0
PX-3 to APX	5646	0
Cisco 4000 to PX-3	623	5023
Cisco 7000 to PX-3	0	5646
Cisco 4000 to Cisco 7000	623	0
Cisco 7000 to Cisco 4000	0	0

Broadcaster generating 900 packets per second

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 to PX-3	6239	0
PX-3 to APX	6239	0
Cisco 4000 to PX-3	1717	4522
Cisco 7000 to PX-3	276	5963
Cisco 4000 to Cisco 7000	1717	0
Cisco 7000 to Cisco 4000	276	0

7. Performance Test Results (Multipoint - UDP Forwarding)

Due to the limited resources and the overall intention of the testing, we restricted the multipoint tests to the PX platforms. The question to be answered was whether the PX-3 would respond the same way as the point to point test but with various interfaces transmitting broadcast traffic. With two broadcasting spoke sites and a single logger hub site we got the following results:

Broadcaster generating 400 packets per second (aggregate) - one site transmitting at 200 pps and a second site transmitting at 200 pps.

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 Hub / PX-3 Spokes	0	0
PX-3 Hub/ APX Spokes	0	0
Cisco 4000 to PX-3	Not Tested	Not Tested
Cisco 7000 to PX-3	Not Tested	Not Tested
Cisco 7000 to Cisco 4000	Not Tested	Not Tested

Broadcaster generating 500 packets per second (aggregate) - one site transmitting at 300 pps and a second site transmitting at 200 pps.

Configuration	*Packets Dropped (Broadcast Side)*	*Packets Dropped (Logger Side)*
PX-3 Hub / PX-3 Spokes	0	2366
PX-3 Hub/ APX Spokes	0	2366
Cisco 4000 to PX-3	Not Tested	Not Tested
Cisco 7000 to PX-3	Not Tested	Not Tested
Cisco 7000 to Cisco 4000	Not Tested	Not Tested

As expected, the aggregate broadcast traffic at the hub site creates the same results. The total process-switching capacity for the PX platform is limited and independent of the interfaces used.

8. Hybrid Bridge/Router Configuration

One configuration that we were able to test was a hybrid bridge/router configuration. Our testing was restricted to the unclassified portion of the network. In this configuration the two spoke locations bridged the serial and Ethernet interfaces. In the hub location, we utilized bridging on the unclassified interfaces and routing for the serial interface going over to the classified portion of the network. With this configuration we were able to successfully pass an aggregate of 600 pps to the logger off the ethernet interface of the hub node. The same file was broadcast from two different bridge segments, so the total number of PDUs broadcast was 23718 packets.

Broadcaster generating 600 packets per second (aggregate) - one site transmitting at 300 pps and a second site transmitting at 300 pps.

Configuration	Packets Dropped (Broadcast Side)	Packets Dropped (Logger Side)
PX-3 Hub / PX-3 Spokes	0	0
PX-3 Hub/ APX Spokes	0	0
Cisco 4000 to PX-3	Not Tested	Not Tested
Cisco 7000 to PX-3	Not Tested	Not Tested
Cisco 4000 to Cisco 7000	Not Tested	Not Tested
Cisco 7000 to Cisco 4000	Not Tested	Not Tested

Broadcaster generating 700 packets per second (aggregate) - one site transmitting at 300 pps and a second site transmitting at 400 pps.

Configuration	Packets Dropped (Broadcast Side)	Packets Dropped (Logger Side)
PX-3 Hub / PX-3 Spokes	0	2594 of 23718 sent
PX-3 Hub/ APX Spokes	0	2594 of 23718 sent
Cisco 4000 to PX-3	Not Tested	Not Tested
Cisco 7000 to PX-3	Not Tested	Not Tested
Cisco 4000 to Cisco 7000	Not Tested	Not Tested
Cisco 7000 to Cisco 4000	Not Tested	Not Tested

Further testing must be done to verify the effects on the traffic sent over the serial connection to the classified logger.

9. Conclusions

- The limitations uncovered during the testing involved the level of process switching capacity on the PX-3, the Cisco 4000, and the Cisco 7000.

- The use of UDP - an inherently unreliable transport mechanism - is not always a suitable choice of transport for data that needs a high level of reliability. The transmission control protocol (TCP) is better suited for reliable transport since it uses sequencing and acknowledgments, but at a cost of increased latency - which was not tested. Also, the use of multicasting or unicasting would take advantage of the fast switching capability of all the routers tested.

- The use of broadcast based networking has an adverse effect on the network. Routing this traffic adds one additional layer of processing (especially when the broadcasts are process switched) and creates multiple copies of each datagram in order to forward it to multiple network subnets. Thus, congesting the network with broadcast traffic. Since the key application relies on broadcasts, we should consider flattening the network and use bridging.

- There were definitive "break points" where the processors could not handle anymore packets. This is true on every platform tested.

- During the testing, we did notice that there were drops on the hold-queue, missed buffer requests, and fallbacks on the interface buffers. To remedy this we added to the hold-queue length and increased the number of permanent big buffers. The actual number of successful packets sent never rose above the initial ceiling. In other words, the addition of buffers and increasing the hold-queue did not affect, in any way, the speed at which the processor process-switched the packets. This was expected.

- It is our best judgment, the limitation is with the router's processor handling UDP broadcasts. With UDP broadcast traffic, all packets are process switched. With unicast and multicast traffic, the router is capable of fast switching most of the packets. Routers gain efficiencies when they are capable of caching routes for packets.

- We had discussions with Technical Assistance Center Staff Engineers from both NET and Cisco Systems over the last two weeks. Engineers from both companies stated that none of their router platforms have ever been tested to find what are the limits of reliable transport of UDP packets.

- The overall configuration relies on the broadcaster. If the network has to reliably transport UDP broadcasts above 400 pps (aggregate) to the hub node to be logged then a PX-3/APX routed solution will not suffice.

10. Recommendations

The initial requirements of the JADS ETE network included a broadcaster transmitting 100 packets per second. All of the configurations tested will satisfy this requirement. Only when the aggregate packet load on the PX-3 (using UDP forwarding) exceeded 400 packets per second was there a concern for lost/dropped packets. With bridging, this ceiling was up to 800 packets per second. If the JADS ETE network is to continue using broadcasted UDP packets with a small number of sites, bridging would be a better solution. Options and limitations are as follows:

<u>Routing</u>

PX-3/APXs - 400 pps aggregate limitation
External Cisco 4000 Routers at each site (serially connected via HSD-2s) - up to 700 pps aggregate limitation; higher cost

Bridging

PX-3/APXs - 800 pps aggregate limitation

Hybrid Routing/Bridging

PX-3/APXs - 600 pps aggregate limitation

Several issues have to be addressed (weighing the pros and cons):

- Broadcasting at lower rates.
  - Pro: Limiting the speed of the broadcasts to under a 400 pps aggregate would ensure the ability to forward all of the UDP traffic through the network.
  - Con: The impact of slower rates on the simulation is unknown.

- The use of multicasting in the future.
  - Pro: The use of multicasting would take advantage of the router's ability to fast switch the traffic. The router only has to process switch the first packet to find the route and will stream the following data along the same route.
  - Con: Finding a suitable data logger may be difficult or a logger would have to be written, and the impact on the simulation is unknown.

- Bridging the entire network.
  - Pro: The use of bridging would increase the reliable throughput of UDP traffic to approximately 800 pps. However, this option should be further tested on the entire JADS ETE network.
  - Con: Speed of transmission is higher, but still limited to 800 pps. Also, it may be difficult to persuade all sites to be part of the same subnet.

- The cost of using external routers.
  - Pro: Different router platforms have different processing power. There are other platforms that have better performance in forwarding UDP packets.
  - Con: There are tangible limitations where the processors could not handle process switched traffic - regardless of platform. Candidate platforms should be tested for this application before procurement. Also, cost is a factor. Costing information is unavailable at this time, but it is safe to state that the more powerful the processor, the higher the cost.

APPENDIX A. ACRONYMS/DEFINITIONS

ADS	Advanced Distributed Simulation
DIS	Distributed Interactive Simulation
DOD	Department of Defense
IP	Internet Protocol: The network layer for the TCP/IP Protocol Suite.
JADS JTF	JOINT ADVANCED DISTRIBUTED SIMULATION JOINT TEST FORCE
JSTARS	Joint Surveillance Targeting and Attack Radar System
LAN	Local Area Network
MAC	Media Access Control: The lower portion of the datalink layer.
MAC-Layer Bridge	A device that connects two or more similar networks in a way that is transparent to the users of the network layer.
OSI	Open Systems Interconnection: The seven layer suite of protocols to be the international standard computer network architecture.
PDU	Protocol Data Unit: An OSI term for "packet." A PDU is a data object exchanged by protocol machines (entities) within a given layer.
PPS	Packets Per Second
T&E	Test and Evaluation
TCP	Transmission Control Protocol: An Internet standard transport protocol in the Internet protocols suite for reliable, connection-oriented, full-duplex streams.
UDP	USER DATAGRAM PROTOCOL: An Internet standard transport protocol that exchanges datagrams without acknowledgments or guaranteed delivery.
WAN	Wide Area Network

All Definitions are from Guide to Networking and Internetworking Terms, Simoneau, Paul, © 1993, American Group, Cary NC

APPENDIX J

Acronyms and Abbreviations

Appendix J - Acronyms and Abbreviations

AAR	after action report/review
ACE	analysis and control element
ADS	advanced distributed simulation
AFATDS	Advanced Field Artillery Tactical Data System
ALQ-131	a mature self-protection jammer system; an electronic countermeasures system with reprogrammable processor developed by Georgia Tech Research Institute
ALSP	aggregate level simulation protocol
ANIU	air network interface unit
AOI	area of interest
ARIES	Advanced Radar Imaging Emulation System
ARPA	Advanced Research Projects Agency
ASAS	All Source Analysis System
ATACMS	Army Tactical Missile System
ATWS	Advanced Technology Work Station
BBS	Brigade Battalion Simulation
BIU	bus interface unit
bps	bits per second
C4I	command, control, communications, computers and intelligence
C4ISR	command, control, communications, computers, intelligence, surveillance and reconnaissance
CAMPS	Compartmented ASAS (All Source Analysis System) Message Processing System
CBS	Corps Battle Simulation
CDP	central data processor
CEP	circular error probable
CGS	common ground station
Cisco	Cisco Systems, Inc.
CPI	coherent processing interval
CPU	central processing unit
deg or °	degree
DFAD	digital feature analysis data
DIS	distributed interactive simulation
DIS NIU	distributed interactive simulation network interface unit
DMA	Defense Mapping Agency
DoD	Department of Defense
DPDU	detonation protocol data unit
DT	developmental testing
DT&E	developmental test and evaluation
DTED	digital terrain elevation data

EAGLE	a rule-based tactical simulation developed by the U.S. Army Training and Doctrine Command (TRAC), Leavenworth, Kansas
ECEF	earth centered earth fixed
ES	entity state
ESPDU	entity state protocol data unit
ETE	End-To-End Test
EW	electronic warfare
FDC	fire direction center
Force	a menu option that opens the Scenario Forces Editor which is used to modify system numbers, aggregation, and task force assignments for a Janus scenario
FPDU	fire protocol data unit
ft or '	feet
FTI	fixed target indicator
FY	fiscal year
GDT	ground data terminal
GIS	Geographical Information System
GNIU	ground network interface unit
GPC	general purpose computer
GRCA	ground reference coverage area
GSM	ground station module
HA	heterogeneous aggregation
hh	hour
HLA	high level architecture
I&Q	in-phase and quadrature (radar data)
ID	identification
IDNX	Integrated Digital Network Exchange
IP	internet protocol
IRIS	internetted range interactive simulations
JAAWS	Janus analyst workstation
JADS	joint advanced distributed simulation or Joint Advanced Distributed Simulation, Albuquerque, New Mexico
JanDIS	Janus Distributed Interactive Simulation
JanPVD	Janus Plan View Display
Janus	interactive, computer-based simulation of combat operations
JCM	joint conflict model
JFS	joint feasibility study or JADS Joint Feasibility Study
Joint STARS	Joint Surveillance Target Attack Radar System
JT&E	joint test & evaluation
JTF	joint test force or Joint Test Force, Albuquerque, New Mexico
km	kilometer
LAN	local area network
LAOI	live area of interest
LFP	live fly phase

LSP	linked simulators phase
LWX	local area network/wide area network exchange
m	meter
M&IS	management and integration software
MB	megabyte
Mbps	megabits per second or millions of bits per second
MIL-STD	military standard
mm	minute
MODSAF	Modular Semi-Automated Forces
MOT&E	multi-service operational test and evaluation
MPDU	message protocol data unit
MPSP	modified programmable signal processor
ms	millisecond
MTI	moving target indicator
NIU	network interface unit
OT	operational test
OT&E	operational test and evaluation
Pd	probability of detection
PDU	protocol data unit
PFA	probability of false alarm
PSP	programmable signal processor
rad	radian
RAM	reliability, availability and maintainability; random access memory
RCU	radar control unit
RDO	radar data operational
RDP	radar data processor
RISS	Radar Image Simulation System
RPS	radar processor simulation
RPSI	radar processor simulator and integrator
RSB	radar sensor bus
RSG	radar sensor group
RSR	radar service request
s / ss / sec	second
S/N	signal-to-noise ratio
SAR	synthetic aperture radar
SCDL	surveillance control data link
SGI	Silicon Graphics, Inc.
SIT	System Integration Test
SM&C	system management and control
SMO	system management officer
SPECTRUM	an instrumentation suite used to measure bandwidth utilization
sq	square
STAGE	Scenario Toolkit and Generation Environment - scripted simulation by Virtual

	Prototypes, Inc., that is used to build complex simulations and graphically define interactive tactical scenarios
STRICOM	U.S. Army Simulation, Training, and Instrumentation Command
SWA	Southwest Asia
T&E	test and evaluation
T-1	digital carrier used to transmit a formatted digital signal at 1.544 megabits per second
TAC	target analysis cell
TAFSM	tactical Army fire support model
TC	target classification
TCAC	Test Control and Analysis Center, Albuquerque, New Mexico
TCP	transmission control protocol
TCS	topocentric coordinate system
TEXCOM	U.S. Army Test and Experimentation Command
TRAC	U.S. Army Training and Doctrine Command (TRADOC) Analysis Center
TRADOC	U.S. Army Training and Doctrine Command
U.S.	United States
U-2R	surveillance aircraft
UAV	Unmanned Aerial Vehicle
UDP	user datagram protocol
V&V	verification and validation
VDP	VSTARS data packet
VSTARS	Virtual Surveillance Target Attack Radar System
VV&A	verification, validation, and accreditation
WAN	wide area network
WGS-84	World Geographic System 1984
WSMR	White Sands Missile Range
X E.R.	times expected rate
XPATCHES	E-8C synthetic aperture radar simulation developed by Wright Laboratory, Dayton, Ohio, and Loral Defense Systems, Goodyear, Arizona